

## PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION  
(PCT Rule 61.2)Date of mailing (day/month/year)  
09 July 2001 (09.07.01)To:  
Commissioner  
US Department of Commerce  
United States Patent and Trademark  
Office, PCT  
2011 South Clark Place Room  
CP2/5C24  
Arlington, VA 22202  
ETATS-UNIS D'AMERIQUE  
in its capacity as elected OfficeInternational application No.  
PCT/GB00/04128Applicant's or agent's file reference  
57.0357WOPCTInternational filing date (day/month/year)  
26 October 2000 (26.10.00)Priority date (day/month/year)  
27 October 1999 (27.10.99)

## Applicant

COUET, Benoit et al

1. The designated Office is hereby notified of its election made: in the demand filed with the International Preliminary Examining Authority on:

05 May 2001 (05.05.01)

 in a notice effecting later election filed with the International Bureau on:2. The election  was was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO  
34, chemin des Colombettes  
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

Pascal Piriou

Telephone No.: (41-22) 338.83.38

## PATENT COOPERATION TREATY

PCT

NOTIFICATION OF THE RECORDING  
OF A CHANGE(PCT Rule 92bis.1 and  
Administrative Instructions, Section 422)

Date of mailing (day/month/year) 12 June 2001 (12.06.01)
Applicant's or agent's file reference 57.0357WOPCT
International application No. PCT/GB00/04128

## From the INTERNATIONAL BUREAU

To:

WANG, William, L.  
Intellectual Property Law  
Department  
Schlumberger Cambridge Research  
Limited  
High Cross  
Madingley Road  
Cambridge CB3 0EL  
ROYAUME-UNI

## IMPORTANT NOTIFICATION

International filing date (day/month/year) 26 October 2000 (26.10.00)
--

## 1. The following indications appeared on record concerning:

the applicant  the inventor  the agent  the common representative

Name and Address SERVICES PETROLIERS SCHLUMBERGER 42, rue Saint Dominique F-75007 Paris France	State of Nationality FR	State of Residence FR
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

## 2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

the person  the name  the address  the nationality  the residence

Name and Address	State of Nationality FR	State of Residence FR
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

## 3. Further observations, if necessary:

The applicant in box 1 is now applicant for FR only.

## 4. A copy of this notification has been sent to:

<input checked="" type="checkbox"/> the receiving Office	<input type="checkbox"/> the designated Offices concerned
<input type="checkbox"/> the International Searching Authority	<input type="checkbox"/> the elected Offices concerned
<input type="checkbox"/> the International Preliminary Examining Authority	<input type="checkbox"/> other:

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No.: (41-22) 740.14.35	Authorized officer Maria Victoria CORTIELLO Telephone No.: (41-22) 338.83.38
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## PATENTS

## PATENT COOPERATION TREATY

DATE RECEIVED 11 MAY 2001

998  
WLW

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## NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

Date of mailing (day/month/year)  
03 May 2001 (03.05.01)Applicant's or agent's file reference  
57.0357WOPCTInternational application No.  
PCT/GB00/04128International filing date (day/month/year)  
26 October 2000 (26.10.00)Priority date (day/month/year)  
27 October 1999 (27.10.99)

## Applicant

SCHLUMBERGER HOLDINGS LIMITED et al

From the INTERNATIONAL BUREAU

To:

WANG, William, L.  
Intellectual Property Law  
Department  
Schlumberger Cambridge Research  
Limited  
High Cross  
Madingley Road  
Cambridge CB3 0EL  
ROYAUME-UNI

NTL PHASE CH. II

DEADLINE: 27 APR 02

Photocopy 11.5.01

Diary 11.5.01

Memotech *already entered*

## IMPORTANT NOTICE

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:

AU,KP,KR,US

In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:

AE,AG,AL,AM,AP,AT,AZ,BA,BB,BG,BR,BY,BZ,CA,CH,CN,CR,CU,CZ,DE,DK,DM,DZ,EA,EE,EP,ES,  
FI,GB,GD,GE,GH,GM,HR,HU,ID,IL,IN,IS,JP,KE,KG,KZ,LK,LR,LS,LT,LU,LV,MA,MD,MG,MK,  
MN,MW,MX,MZ,NO,NZ,OA,PL,PT,RO,RU,SD,SE,SG,SI,SK,SL,TJ,TM,TR,TT,TZ,UA,UG,UZ,VN,YU,  
The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).

3. Enclosed with this Notice is a copy of the international application as published by the International Bureau on 03 May 2001 (03.05.01) under No. WO 01/31328

## REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, a demand for international preliminary examination must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

## REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

If the applicant wishes to proceed with the international application in the national phase, he must, within 20 months or 30 months, or later in some Offices, perform the acts referred to therein before each designated or elected Office.

For further important information on the time limits and acts to be performed for entering the national phase, see the Annex to Form PCT/IB/301 (Notification of Receipt of Record Copy) and Volume II of the PCT Applicant's Guide.

The International Bureau of WIPO  
34, chemin des Colombettes  
1211 G neva 20, Switzerland

Facsimile No. (41-22) 740.14.35

Authorized officer

J. Zahra

Telephone No. (41-22) 338.83.38

Case No. 57.0357 WO PCT

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## PATENT COOPERATION TREATY

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REC'D 06 DEC 2001  
WIPO PCT

## INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 57.0357WOPCT	<b>FOR FURTHER ACTION</b> See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/04128	International filing date (day/month/year) 26/10/2000	Priority date (day/month/year) 27/10/1999
International Patent Classification (IPC) or national classification and IPC G01N29/02		
<p>Applicant  <b>SERVICES PETROLIERS SCHLUMBERGER</b> <b>SCHLUMBERGER HOLDINGS LIMITED</b></p>		
<p>1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.</p> <p>2. This REPORT consists of a total of 7 sheets, including this cover sheet.</p> <p><input type="checkbox"/> This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).</p> <p>These annexes consist of a total of sheets.</p>		
<p>3. This report contains indications relating to the following items:</p> <ul style="list-style-type: none"> <li>I <input checked="" type="checkbox"/> Basis of the report</li> <li>II <input type="checkbox"/> Priority</li> <li>III <input type="checkbox"/> Non-establishment of opinion with regard to novelty, inventive step and industrial applicability</li> <li>IV <input checked="" type="checkbox"/> Lack of unity of invention</li> <li>V <input checked="" type="checkbox"/> Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement</li> <li>VI <input type="checkbox"/> Certain documents cited</li> <li>VII <input type="checkbox"/> Certain defects in the international application</li> <li>VIII <input type="checkbox"/> Certain observations on the international application</li> </ul>		

Date of submission of the demand 05/05/2001	Date of completion of this report 05.12.2001
Name and mailing address of the international preliminary examining authority:  European Patent Office - P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk - Pays Bas Tel. +31 70 340 - 2040 Tx: 31 651 epo nl Fax: +31 70 340 - 3016	Authorized officer Hocquet, A Telephone No. +31 70 340 2928



# INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/04128

## I. Basis of the report

1. With regard to the **elements** of the international application (*Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17)*):  
**Description, pages:**

1-32 as originally filed

### Claims, No.:

1-25 as originally filed

### Drawings, sheets:

1/11-11/11 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- the language of publication of the international application (under Rule 48.3(b)).
- the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- contained in the international application in written form.
- filed together with the international application in computer readable form.
- furnished subsequently to this Authority in written form.
- furnished subsequently to this Authority in computer readable form.
- The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- the description, pages:
- the claims, Nos.:

**INTERNATIONAL PRELIMINARY  
EXAMINATION REPORT**

International application No. PCT/GB00/04128

the drawings,        sheets:

5.  This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c));  
*(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)*

6. Additional observations, if necessary:

**IV. Lack of unity of invention**

1. In response to the invitation to restrict or pay additional fees the applicant has:

restricted the claims.

paid additional fees.

paid additional fees under protest.

neither restricted nor paid additional fees.

2.  This Authority found that the requirement of unity of invention is not complied and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

complied with.

not complied with for the following reasons:

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

all parts.

the parts relating to claims Nos. .

**V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Yes:      Claims 3-7,9-25
	No:      Claims 1, 2, 8
Inventive step (IS)	Yes:      Claims 11,14,15
	No:      Claims 1-10, 12-13, 16-25

**INTERNATIONAL PRELIMINARY  
EXAMINATION REPORT**

International application No. PCT/GB00/04128

Industrial applicability (IA) Yes: Claims 1-25  
No: Claims

2. Citations and explanations  
see separate sheet

**INTERNATIONAL PRELIMINARY  
EXAMINATION REPORT - SEPARATE SHEET**

International application No. PCT/GB00/04128

**R It m I**

**Basis of the opinion**

Reference is made to the following documents:

D1: US-A-5 661 233 (SPATES) 26 August 1997 cited in the application  
D2: US-A-3 341 835 (WERNER) 12 September 1967  
D3: US-A-5 159 838 (LYNNWORTH) 3 November 1992  
D4: EMMONS ET AL.: 'on-site, near real time monitoring of scale deposition'  
PROCEEDINGS OF SPE 1999 CONFERENCE ' PRODUCTION OPERATIONS  
AND ENGINEERING', vol. 2, 3 - 6 October 1999, pages 389-394, XP000979810  
Houston (USA) cited in the application

**Re Item IV**

**Lack of unity of invention**

The subject-matter common to claims 1 and 16 can be summarised as ' A deposit monitoring apparatus located in a hydrocarbon wellbore, comprising: a deposit monitor adapted to measure deposition of material on a monitoring surface that is directly exposed to fluids in the hydrocarbon wellbore; a power supply adapted to supply said monitor with electrical energy'. All these technical features are known from the state of the art (see for example D4, passages cited in the International Search Report (ISR)). The remaining technical features of claim 1 (measuring a change in resonance frequency of an acoustic device) and of claim 16 (having a deposit removal system in a control loop with the monitor) are neither identical nor corresponding in the sense of Rule 13.2 PCT.

Therefore, the sets of claims 1-15 and 16-25 do not fulfill the requirements of unity of invention of Rule 13 PCT.

**Re Item V**

Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

- 1 D4 discloses a deposit monitoring apparatus comprising: an acoustic device adapted to operate in a resonance mode including a monitoring surface directly exposed to fluids wherein the deposition of material on the monitoring surface is monitored by measuring a change in resonance frequency of the acoustic device

(see passages cited in the ISR); and a power supply adapted to supply said monitor with electrical energy (idem). The device of D4 is primarily used on collected brines in test cells, but D4 mentions that the method has potential as on-line monitoring tool mounted either permanently or quasi-permanently in the wellbore (idem). As no feature in claims 1, 2, 8 goes beyond the features of the tool described in D4, these claims do not satisfy the criterion of novelty set forth in Article 33(2) PCT.

- 2 The subject-matter of claims 3-8, 17, 19, 20, 21, 23 all concern designs options known in the art of deposit monitoring which would have been used by a skilled person, specially considering the problems mentioned in D4 for the online implementation of the monitoring of deposits by an acoustic device in downhole applications (D4, page 392, column 1, last paragraph). They do not satisfy the criterion set forth in Article 33(3) PCT for the following reasons:
  - 2.1 D4 mentions that on-line downhole monitoring implies extreme temperature and pressures environments. The skilled person would therefore consider acoustic sensors of rugged construction used in online applications, such as described for example in D2 or D3. D2 describes a deposit monitoring device using a tube guiding the vibrations of a magnetostrictive or piezoelectric transducer and vibrating longitudinally at 20-40 KHz for sensing on-site the solidification of ice on a monitoring surface. D3 relates to the design of ultrasonic sensors designed for on-line process control applications in extreme temperature and pressures environments. D3 teaches the use of longitudinal waves around 100 KHz emitted from piezoelectric or magnetostrictive transducers guided through a buffer rod similar to acoustic horns (see D3, column 1, lines 10-column 2, line 4, column 7, line 64 to column 8 line 27, figure 3). the skilled person would regard it a normal design procedure to combine all the features set out in claims 3-7. Thus, the subject-matter of claims 3-7 does not involve an inventive step.
  - 2.2 D1 discloses a deposit monitoring apparatus located in a hydrocarbon wellhead (col. 14, line 6) comprising: an acoustic device adapted to operate in a resonance mode including a monitoring surface directly exposed to fluids in a hydrocarbon wellhead or pipeline, wherein the deposition of material on the monitoring surface is monitored by measuring a change in resonance frequency of the acoustic device (column 7, lines 54-57); and a power supply adapted to supply said monitor with electrical energy (idem). The acoustic device is mounted either

**INTERNATIONAL PRELIMINARY  
EXAMINATION REPORT - SEPARATE SHEET**

International application No. PCT/GB00/04128

permanently or quasi- permanently in the wellhead or pipeline (see column 14, line 6). D1 and D4 relate therefore to similar monitoring tools and the skilled person would naturally use the solutions of D1 for problems already mentioned in D4. D4 indicates that one of the problem of the implementation of an on-line tool is that the sensitivity of the acoustic mass sensor decreases when the deposit is too important. D1 solves this problem by further providing a deposit removal system adapted to at least partially remove the deposition from the monitoring surface, the deposit removal system being in a control loop with said deposit monitor (col. 14, lines 10-14), wherein the deposit removal system includes a deposition inhibiting or removing chemical agent (idem). The deposit removal system is placed near a sensor (the monitoring surface) having a surface exposed to the fluids (col 13, lines 55-65). D1 mentions also the use of 'elements adapted to exert a physical force' (mechanical scraping) for deposit removal (D1, col. 14, line 5) The subject-matter of claims 9, 10, 12, 13, 16-18, 22-25 does thus not imply an inventive step for the skilled person using D4 and D1.

- 2.3 Similarly, D2, already referred to in paragraph 2.1 above, foresees a deposit removal system for the same reason. The subject-matter of claims 16 and 18-21 does thus not imply an inventive step for the skilled person using D4 and D2.
- 3 Although D1 mentions the use of mechanical scraping for deposit removal (D1, col. 14, line 5), and D2 mentions the use of the heat produced by the acoustic device for deposit removal (D2, col. 8, lines 8-17), none of the documents of the ISR discloses a deposit removal system which uses the acoustic device to exert a physical force onto the deposited material. The combination of the features of dependent claim 11 is thus neither known from, nor rendered obvious by, the available prior art.
- 4 The combination of the features of dependent claim 15 is neither known from, nor rendered obvious by, the available prior art, which does not disclose or suggest to include in the sensor of claim 1 an additional sensing system to analyze material deposited.

## PATENT COOPERATION TREATY

## PCT

## INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference <b>57.0357WOPCT</b>	<b>FOR FURTHER ACTION</b> see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. <b>PCT/GB 00/04128</b>	International filing date (day/month/year) <b>26/10/2000</b>	(Earliest) Priority Date (day/month/year) <b>27/10/1999</b>
Applicant <b>SCHLUMBERGER HOLDINGS LIMITED et al.</b>		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 4 sheets.

It is also accompanied by a copy of each prior art document cited in this report.

**1. Basis of the report**

a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

contained in the international application in written form.

filed together with the international application in computer readable form.

furnished subsequently to this Authority in written form.

furnished subsequently to this Authority in computer readable form.

the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2.  **Certain claims were found unsearchable** (See Box I).

3.  **Unity of invention is lacking** (see Box II).

4. With regard to the **title**,

the text is approved as submitted by the applicant.

the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

the text is approved as submitted by the applicant.

the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No.

as suggested by the applicant.

because the applicant failed to suggest a figure.

because this figure better characterizes the invention.

1b

None of the figures.

## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 00/04128

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01N29/02 G01G3/16 B08B7/02 E21B37/00 G01N5/00  
G01N33/28

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01N G01G B08B E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 661 233 A (SPATES JAMES J ET AL) 26 August 1997 (1997-08-26) cited in the application column 2, line 30 – line 38 column 4, line 10 – line 25 column 8, line 20 – line 62 column 13, line 20 – line 28 column 13, line 55 – line 65 column 14, line 4 – line 38 --- -/-	1, 16

 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

## \* Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*&\* document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 February 2001	21/02/2001
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer  Hocquet, A

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 00/04128

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EMMONS ET AL.: "on-site, near real time monitoring of scale deposition" PROCEEDINGS OF SPE 1999 CONFERENCE 'PRODUCTION OPERATIONS AND ENGINEERING', vol. 2, 3 - 6 October 1999, pages 389-394, XP000979810 Houston (USA) cited in the application page 392, column 1, paragraph 4 -column 2, paragraph 3 page 390, column 2, paragraph 1 - paragraph 2 ---	1,16
X	US 5 969 235 A (ALLAN GRAEME) 19 October 1999 (1999-10-19) cited in the application column 3, line 42 -column 4, line 19; figures	1
X	column 1, line 9 - line 14 ---	16
X	US 5 646 338 A (DECLERCQ GHISLAIN ET AL) 8 July 1997 (1997-07-08) column 1, line 19 - line 54 column 5, line 50 - line 60 column 6, line 17 - line 39 column 8, line 30 - line 51 column 9, line 12 - line 43 ---	1,16
A	US 5 595 243 A (MAKI JR VOLDI E ET AL) 21 January 1997 (1997-01-21) column 4, line 38 - line 41 column 5, line 5 - line 16; figures 3-5 ---	1,16
A	US 5 159 838 A (LYNNWORTH LAWRENCE C) 3 November 1992 (1992-11-03) column 1, line 10 - line 19 column 12, line 20 - line 34 column 1, line 63 -column 2, line 4 column 10, line 20 - line 45; table I ---	3-6
A	US 5 889 209 A (PIEDRAHITA RAUL H ET AL) 30 March 1999 (1999-03-30) cited in the application the whole document ---	8,24
A	US 3 341 835 A (WERNER) 12 September 1967 (1967-09-12) column 4, line 67 -column 5, line 2; figures column 7, line 7 - line 13 column 7, line 48 - line 73 column 8, line 6 - line 19 ---	6
A	11,24 -/-	

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 00/04128

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 112 642 A (WAJID ABDUL) 12 May 1992 (1992-05-12) column 1, line 5 – line 14 column 1, line 40 – line 49 column 9, line 39 – line 54 -----	1

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 00/04128

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5661233	A	26-08-1997	US	5827952 A	27-10-1998
US 5969235	A	19-10-1999	AU	3795099 A	03-02-2000
US 5646338	A	08-07-1997	GB	2291520 A	24-01-1996
			AU	2897495 A	04-03-1996
			CA	2195330 A	15-02-1996
			EP	0774108 A	21-05-1997
			FI	970413 A	31-01-1997
			GB	2292226 A	14-02-1996
			WO	9604529 A	15-02-1996
			NO	970403 A	01-04-1997
			ZA	9506311 A	14-03-1996
			AU	690715 B	30-04-1998
			BR	9508485 A	30-12-1997
			DE	69504856 D	22-10-1998
			DE	69504856 T	18-03-1999
			NZ	289206 A	26-01-1998
US 5595243	A	21-01-1997	NONE		
US 5159838	A	03-11-1992	NONE		
US 5889209	A	30-03-1999	NONE		
US 3341835	A	12-09-1967	NONE		
US 5112642	A	12-05-1992	DE	4035240 A	02-10-1991
			GB	2242523 A,B	02-10-1991
			JP	2974253 B	10-11-1999
			JP	3285108 A	16-12-1991

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
3 May 2001 (03.05.2001)

PCT

(10) International Publication Number  
**WO 01/31328 A1**

(51) International Patent Classification<sup>7</sup>: **G01N 29/02**, G01G 3/16, B08B 7/02, E21B 37/00, G01N 5/00, 33/28

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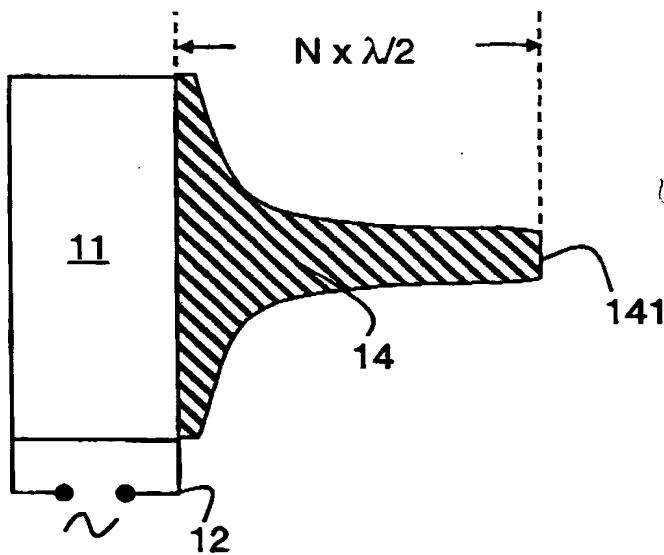
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(54) Title: DOWNHOLE DEPOSITION MONITORING SYSTEM



(57) Abstract: Described is a downhole apparatus for detecting and removing deposits from a surface exposed to wellbore fluids. The apparatus can monitor the rate of deposition and subsequently remove the deposited material. The combination of detection apparatus and removal apparatus provides a downhole instrument with self-cleaning operation mode.

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### Downhole Deposition Monitoring System

This invention relates to apparatus and methods for monitoring solid deposits of material in a wellbore and operating downhole sensors and other wellbore equipment. Particularly, the invention relates to such apparatus and methods for sensing and removing solid deposits in hydrocarbon wells.

10

#### BACKGROUND OF THE INVENTION

The formation of both organic and inorganic deposits in the near wellbore region of producing formations and on the tubing of a producing hydrocarbon well can be a major and costly problem.

15 See, e.g. Allen, T.O. and Roberts, A.P., *Production Operations*, Vol. 2, 2nd edition, pp. 11-19 and 171-181, OGCI, Tulsa, Ok. (1982); Cowan, J.C and Weintritt, D.J., *Water-formed Scale Deposits*, Gulf Publishing Co., Houston (1976). The deposits can seriously impede the productivity of wells by reducing the near 20 wellbore permeability of producing formations and progressively restrict the diameter of the tubing.

The formation of inorganic deposits, or scale, is caused by the precipitation of inorganic salts from produced water. Calcium 25 carbonate scale is usually formed by the change in the pressure and temperature of the produced water in the near wellbore and in the production tubing. Barium, strontium and calcium sulphate scales are usually formed by the mixing of formation water and seawater injected into producing wells; the high concentration 30 of sulphate in seawater mixes with the high concentrations of divalent cations in formation waters with the resulting precipitation of the sulphate salts. The formation of scale may be partly prevented by water shut-off treatments and the use of scale inhibitors. Once formed, scale can be removed only with 35 some difficulty; calcium carbonate scale can be dissolved by

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mineral acids and barite scale can be removed by milling or scale dissolvers such as EDTA. See, e.g. Putnis, A, Putnis, C.V. and Paul, J.M., "The efficiency of a DTPA-based solvent in the dissolution of barium sulfate scale deposits", *SPE International Symp. Oilfield Chemistry*, San Antonio, Texas, February 1995, SPE 29094.

5 In extreme cases the production tubing must be removed and replaced, although the presence of radioactive scale (due to the presence of radium salts) can make scale disposal an environmental issue.

10

The production of hydrocarbons frequently causes the precipitation of organic precipitates such as paraffin waxes and asphaltenes. These organic precipitates are caused by changes in the pressure and temperature of the produced fluids in the near 15 wellbore. The precipitates can be removed with solvent washes, although the disposal of the solvent after cleaning represents an increasing environmental problem.

20 The solubility of various inorganic and organic species can be predicted from thermodynamic models of the electrolyte solutions or hydrocarbons. See, e.g. Jasinski, R, Taylor, K. and Fletcher, P., "Calcite scaling - North Sea HTHP wells", *SPE Symp. Oilfield Scale*, Aberdeen, January 1999; Calange, S., Ruffier-Meray, V. and Behar, E., "Onset crystallization 25 temperature and deposit amount for waxy crudes: experimental determination and thermodynamic modelling", *SPE International Symp. Oilfield Chemistry*, Houston, Texas, February 1997, SPE 37239. However, thermodynamic models are essentially 30 equilibrium models and they cannot predict any details of the precipitation process such as the location of precipitation, the rate of precipitation or the degree of supersaturation that the fluid can tolerate.

35 Several patents and papers have described both acoustic and non-acoustic methods for sensing the formation of scale in producing

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hydrocarbon wells and similar environments. An acoustic method for measuring the thickness of metal oxide corrosion products on the inside of boiler tubes has been described. See Lester, S.R., "High frequency ultrasonic technique for measuring oxide scale on the inner surface of boiler tubes", *US Patent 4,669,310*, June 2, 1987. The thickness of oxide scale is determined by the time of flight of an acoustic pulse applied from the external surface of the pipe. The frequency of the acoustic pulse was 50 MHz, which enabled a scale thickness of approximately 0.1 mm to be detected. The use of an automated ultrasonic inspection system for determining the thickness of scale formation which has formed on the inside of heat transfer tubes in boilers has been described. See Okabe, Y., Iwamoto, K., Torichigai, M., Kaneko, S., Ichinari, J. and Koizumi, K., "Automated ultrasonic examination system for heat transfer tubes in a boiler", *US Patent 4,872,347*, October 10, 1989. A rotating transducer was inserted into the tubes and their diameter as a function of location determined by the reflection of sound from the scale-water interface. An acoustic wireline logging tool, Schlumberger's Cement Evaluation Tool (CET), has been used to determine the accumulation of scale on the casing of geothermal wells. See, *US Patent No 5,072,388*, to O'Sullivan et al. The interfaces between the scale and wellbore fluid and the scale and the casing are determined by the transit time of the acoustic waves, which have a frequency of approximately 0.5 MHz. *US Patent 5,092,176* disclosed a method for determining the thickness of scale on the inside of a water pipe by the attenuation of acoustic energy emitted and received by a transducer on the outside of the pipe. The optimum frequency range for the ultrasound was observed to be 3-7 MHz. For example, measurements made using ultrasound below a frequency of 3 MHz gave poor sensitivity to scale thickness and beam spreading was observed to be a problem. An acoustic method of identifying scale types and scale thickness in oil pipelines using the attenuation in the reflected acoustic signal from a

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tool that is moved through the inside of the pipe has been described. See, Gunarathne, G.P.P. and Keatch, R.W., "Novel techniques for monitoring and enhancing dissolution of mineral deposits in petroleum pipelines", *SPE Offshore Europe*

5 Conference, Aberdeen, Sept. 1995, SPE 30418 (hereinafter "Gunarathne"); Gunarathne, G.P.P. and Keatch, R.W., "Novel techniques for monitoring and enhancing dissolution of mineral deposits in petroleum pipelines", *Ultrasonics*, 34, 411-419 (1996) (hereinafter "Gunarathne and Keatch"). The frequency of  
10 the ultrasound used was in the range 3.5-5.0 MHz, which allowed the thickness of barium sulphate scale on steel to be measured to an accuracy of  $\pm 0.5$  mm.

US Patent 5,661,233 (hereinafter "Spates et al.") disclosed  
15 several acoustic-wave devices for determining the deposition of organic precipitates, such as paraffin wax, on to a sensing surface immersed in a petroleum-based fluid. The acoustic measurements were made with devices using various acoustic modes: surface acoustic waves and thickness shear, acoustic  
20 plate and flexural plate modes. The devices measured changes in the damping voltage and resonant frequency of the device as the wax precipitate formed, although no details were disclosed regarding the operating frequencies of the acoustic devices or the acoustic power they generated. Spates et al. discussed  
25 periodic cleaning of the sensing surface of the acoustic device by heating the surface to melt the paraffin wax. However, the use of acoustic energy to clean the organic precipitates from the acoustic sensor was not disclosed or suggested. Several applications of the measurement of wax accumulation were  
30 described, including location of acoustic devices on the sea floor to monitor the production of hydrocarbon from oil wells and guide well treatments. The application of a quartz microbalance to measure simultaneously mass loading and liquid properties has been described. See, US Patent 5,201,215;  
35 Martin, S.J., Granstaff, V.E. and Frye, G.C., "Characterisation

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of a quartz crystal microbalance with simultaneous mass and liquid loading", *Anal. Chem.*, **63**, 2272-2281 (1991) (collectively hereinafter "Granstaff and Martin"). The authors used changes in the resonant frequency and magnitude of the maximum 5 admittance of a quartz microbalance to differentiate between changes in the mass of material deposited from a liquid and changes in the properties of the liquid (density and viscosity). The operating frequency of the quartz microbalance was close to 5 MHz, at which value the resonator was able to detect solid 10 films of the order of 0.1  $\mu\text{m}$  in thickness.

The application of an on-line quartz crystal microbalance to monitor and control the formation of organic and inorganic precipitates from hydrocarbons and water has been described. 15 See, US Patent 5,734,098 (hereinafter "Kraus et al."). The quartz crystal microbalance consisted of a thickness-shear mode resonator and was described by Kraus et al. as being substantially similar to those disclosed by Granstaff and Martin. Kraus et al. described the use of the thickness-shear 20 mode resonator for the on-line measurement of scaling, corrosion and biofouling in industrial processes. They also described the use of the measurement of deposit formation to determine the treatment required to correct the industrial process and prevent continual deposit formation, e.g., by use of a chemical additive 25 such as an inorganic scale inhibitor. Although Kraus et al. described the use of a thickness-shear mode resonator to monitor deposit formation from hydrocarbons, industrial water and their mixtures (including emulsions), no disclosure or suggestion was made to the operation of these sensors in or near producing 30 hydrocarbon wells, on either a temporary or permanent basis. Additionally, there was no disclosure or suggestion regarding the treatment of producing hydrocarbon wells, for either organic or inorganic deposit formation, on the basis of measurements made by these sensors.

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A laboratory acoustic resonance technique to determine the onset of the precipitation of wax and asphaltene from produced hydrocarbons has been described. See, Sivaraman, A., Hu, Y., Thomas, F.B., Bennion, D.B. and Jamaluddin, A.K.M., "Acoustic resonance: an emerging technology to identify wax and asphaltene precipitation onset in reservoir fluids", *48th Annual Tech. Meet. The Petroleum Society*, Calgary, Canada, June 8-11, 1997, paper CIM 97-96; Jamaluddin, A.K.M., Sivaraman, A., Imer, D. Thomas, F.B. and Bennion, D.B., "A proactive approach to address solids (wax and asphaltene) precipitation during hydrocarbon production", *8th Abu Dhabi Intern. Petroleum Exhibit.*, Abu Dhabi, U.A.E., 11-14 October, 1998, SPE 49465. The spectrum of resonant frequencies of a sample of liquid hydrocarbon in a cylinder of fixed length and cross-sectional area was obtained as a function of temperature and pressure. The resonant spectra were collected using two ultrasonic transducers operating over the frequency range 0-40 kHz, although significant resonances were observed only over the frequency range 5-35 kHz. The precipitation of wax and/or asphaltene from the liquid hydrocarbon sample as the pressure and temperature of the sample was changes resulted in changes in the frequency of the resonances and changes in their amplitude. The changes in the resonant spectra were attributed to changes velocity of sound in the liquid. No reference was made to the precipitation of wax or asphaltene on the transmitting or receiving transducer.

The use of a thickness-shear mode resonator to monitor the formation of barium sulphate in samples of produced water collected at the well head has been described. See, Emmons, D.H. and Jordan, M.M., "The development of near-real time monitoring of scale deposition", *SPE Oilfield Scale Symposium*, Aberdeen, 27-28 Jan., 1999 (hereinafter "Emmons and Jordan"). The resonator was immersed in a fixed volume of produced water and known amounts of soluble barium ions were added to precipitate barium sulphate scale. The resonator detected the

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formation of scale on its sensing surface by a decrease in resonant frequency. The amount of barium added before scale formation was detected by the resonator gave an indication of the level of inhibition in the produced water. Emmons and Jordan 5 argued that the formation of scale by small additions of barium ions indicated the produced water was close to scaling and treatment of the well by a suitable scale inhibitor was required. Note that this method of monitoring scale formation is not an *in situ* method and does not measure the spontaneous 10 formation of scale under downhole conditions of temperature, pressure, composition and flow. In addition, the resonator was not able to clean the scale from its sensing surface. A quartz crystal microbalance to monitor the formation of calcium carbonate scale under laboratory conditions has been described. 15 See, Gabrielli, C., Keddam, M., Khalil, A., Maurin, G., Perrot, H., Rosset, R. and Zidoune, M., "Quartz crystal microbalance investigation of electrochemical calcium carbonate scaling", *J. Electrochem. Soc.*, **145**, 2386-2395 (1998). The resonant frequency of the microbalance was 6 MHz and calcium carbonate 20 deposition rates of 200-400  $\mu\text{g}/\text{cm}^2$  per hour were measured. The calcium carbonate scale was observed to be the mineral calcite, which, with an assumed density of 2.71  $\text{g}/\text{cm}^3$ , gave deposits of 0.7-1.5  $\mu\text{m}$  in thickness. The rate of scale accumulation measured by the quartz microbalance was compared with a standard 25 electrochemical scale monitor that measured the redox current passing through an electrode as water was reduced. The decline in redox current gave an indirect measure of the decrease in the surface area of the electrode as it was covered with scale and was observed to be less sensitive to scale formation than the 30 quartz crystal microbalance. The use of a piezoelectric quartz crystal to monitor the fouling of surfaces in a water cooling tower by inorganic scale and bacterial growth at ambient conditions has been described. See, Nohata, Y. and Taguchi, H., "An ultrasensitive fouling monitoring system for cooling 35 towers", *Materials Performance*, **34**, 43-46 (1995) (hereinafter

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"Nohata and Taguchi"). Although Nohata and Taguchi did not specifically disclose the operating frequency of the quartz crystal, a value of about 5 MHz can be deduced from the measured accumulation rates of 1-20  $\mu\text{g}/\text{cm}^2$  per day.

5

The use of a tuning fork for measuring the deposition of scale in a surface process system has been disclosed. See, US Patent 5,969,235. The accumulation of scale on the tines of the tuning fork causes a shift in the characteristic vibrating frequency of 10 the tuning fork as measured by a suitable electronic device, such as a piezoelectric cell. The change in vibrating frequency of the tuning fork, indicating the deposition of scale, was used to control the addition of scale inhibitor to the process stream.

15

Non-acoustic scale sensing techniques have also been reported. A method of determining the accumulation of scale in petroleum pipelines using a heat transfer sensor has been described. See, US Patent 4,718,774. The scale formed on the external wall of 20 the sensor impeded the loss of heat from a heating element in the sensor to the fluid flowing in the pipeline. The decrease in heat flow was measured by means of a temperature sensor. A wellbore scale monitor that measured the radioactivity of the radium salts precipitated with other alkaline earth metal salts 25 has been described. See, US Patent 4,856,584 (hereinafter "Sneider"). Sneider discloses the use of measurements of scale radioactivity to indicate when and where the placement of scale inhibitor is required. Another scale monitoring technique is disclosed in US Patent 5,038,033; the radioactivity of the scale 30 was detected by a wireline gamma ray detector, correcting for the natural gamma radiation emitted from the surrounding rock formations.

Accurately measured pressure drops over various sections of a 35 reinjection pipeline in a geothermal power plant has been used

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to monitor the growth of silica scale. See, Stock, D.D., "The use of pressure drop measurements to monitor scale build-up in pipelines and wells", *Geothermal Resources Council Trans.*, **14**, 1645-1651 (1990). The measured pressure drops across the 5 sections of pipe produced friction factors in the range 0.1-0.2, compared to an expected value of 0.01. Cleaning the silica scale from the pipeline sections using a wire brush pig resulted in the friction factor dropping below a value of 0.06. Both 10 laboratory and field systems to evaluate the scaling potential of oilfield brine samples by monitoring the pressure drop across a capillary tube through which the brine flows and deposits scale are being currently produced by the company Oilfield Production Analysts Ltd. (see product brochures for P-MAC 2000, 3000 and 4000 series). Three optical techniques to monitor 15 fouling in industrial process systems were described in Flemming, H-C., Tamachkiarowa, A., Klahre, J. and Schmitt, J., "Monitoring of fouling and biofouling in technical systems", *Water Sci. Tech.*, **38**, 291-298 (1998). The techniques consisted of measurement of the intensity of light reflected from a small 20 optical fibre probe, the measurement of turbidity through optical windows in a flow line (using periodically cleaned windows in the flow line as a reference optical pathlength) and an infrared spectroscopy flow cell. The accumulation of deposits and the chemical nature of the deposits on the optical windows 25 of the infrared flow cell could be determined from the infrared spectra.

A number of published reports have described the application of sonic energy for cleaning producing oil wells and equipment in 30 similar industrial processes. A method of cleaning downhole deposits, such as tar, from producing formations and production tubing was disclosed in US Patent 3,970,146. However, no details were given of the power or frequency of the sound used for wellbore cleaning. A low frequency (20-100 Hz) vibrating device 35 for cleaning deposits on the walls of casing and tubing and in

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formations and gravel packs was disclosed in US Patent 4,280,557. The vibrations were generated in the device by an orbiting mass on an unbalanced rotor, which, in turn, produced a whirling vibratory pressure of large amplitude in the fluid in 5 the annulus. US Patent 4,320,528 disclosed a method of removing iron oxide corrosion products and other scaling deposits from the pipes of steam generators using a combination of high power sound and a high-temperature solvent (e.g., sodium EDTA, citric acid and a corrosion inhibitor). The acoustic transducers 10 operated in the frequency range 2-200 kHz and generated an output acoustic power greater than 0.2 W/cm<sup>2</sup>, a value which is above the cavitation threshold of aerated water at ambient pressure and temperature. See, Esche, R., "Untersuchung der Schwingungkavitation in Flüssigkeiten", *Acustica*, 2, AB208-218 15 (1952); Mason, T.J. and Lorimer, J.P., *Sonochemistry: Theory, Applications and Uses of Ultrasound in Chemistry*, p 31, Ellis Horwood, Chichester, UK (1988). The transducers were located permanently on the outside of the heat exchanger tubes. US 20 Patent 4,444,146 disclosed an ultrasonic method to clean the fouled surfaces of submerged structures, such as the hulls of ships. The ultrasonic cleaner consisted of two ultrasonic transducers focussed on a small area of surface to be cleaned. The transducers operated at slightly different frequencies, typically in the range 180-210 kHz; no details were disclosed on 25 the acoustic power required to clean the fouled surfaces. UK Patent Application 2 165 330 A (hereinafter "D'Arcy et al.") disclosed a method of cleaning underwater structures to depths of up to 1000 metres using focussed ultrasound in the frequency range 40-100 kHz. The ultrasound was generated and focussed 30 using an array of transducers located on the concave surface of a spherical cap. The density of acoustic power at the focal point of the array of transducers was stated to be about 500 W/cm<sup>2</sup>, a value that is approximately 3 orders of magnitude above the cavitation threshold of water at ambient pressure. D'Arcy et 35 al. suggested the high power acoustic array could be used to

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clean the base of oil production platforms. US Patent 5,184,678 disclosed the design of a high power acoustic logging tool to stimulate fluid production from oil wells. The acoustic power was provided by pulsed magnetostrictive transducers operating in 5 the frequency range 5-30 kHz and emitting an acoustic power density of up to  $1 \text{ W/cm}^2$ . The tool was designed to give a stand-off from the treated formation of  $0.2\text{--}0.5\lambda$ , where  $\lambda$  is the wavelength of the sound in the borehole fluid. The treated formations were exposed to the acoustic power for periods of 5- 10 60 minutes. According to US Patent 5,184,678, the applied ultrasound reduced the viscosity of the fluid in permeable formations and fluidised the particulate matter, thus facilitating its removal.

15 It has been shown that ultrasound applied at a frequency of 10 kHz could remove asphaltene deposits from a sand pack saturated with both water and kerosene at ambient pressure. See, Gollapdi, U.K., Bang, S.S. and Islam, M.R., "Ultrasonic treatment for removal of asphaltene deposits during petroleum 20 production", *SPE International Conf. Formation Damage Control*, Lafayette, Louisiana, February 1994, SPE 27377. Although the acoustic power applied to the sand packs during cleaning was not measured, the ultrasonic transducer could generate a maximum output acoustical power of 250 W. The authors discussed the role 25 of acoustic cavitation in the cleaning process and acoustic cavitation was undoubtedly achieved at the power settings reported. The asphaltene deposits were observed to be removed significantly more efficiently by the ultrasound in kerosene than in water. It has been demonstrated under laboratory 30 conditions that the damage caused to permeable formation by the invasion of clay particles from drilling fluids can be partially removed by the application of high power ultrasound. See, Venkitaraman, A., Roberts, P.M. and Sharma. M.M., "Ultrasonic removal of near-wellbore damage caused by fines and mud solids", 35 *SPE Drilling & Completions*, 10, 193-197 (1995). Two ultrasonic

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transducers were used; one was a high power ultrasonic horn operating at a frequency of 20 kHz with an output power of up to 250 W and the other was a low power transducer operating over frequency range 10-100 kHz. The same authors subsequently

5 evaluated the application of high power ultrasound under laboratory conditions for the removal of organic deposits and formation damage caused by the invasion of drilling fluid filtrate containing water-soluble polymers. See, Roberts, P.M., Venkitaraman, A. and Sharma, M.M., "Ultrasonic removal of  
10 organic deposits and polymer induced formation damage", *SPE Formation Damage Control Symp.*, Lafayette, Louisiana, February 1996, SPE 31129. Using the same ultrasonic transducers, it was demonstrated that polymer-induced formation damage was considerably more difficult to remove than the damage caused by  
15 clay fines. However, formation damage resulting from the precipitation of wax in the test core samples could be removed by sonication when the core samples were soaked in a suitable solvent.

20 US Patent 5,595,243 disclosed the use of a general purpose acoustic cleaning tool for improving the near wellbore permeability of producing formations by redissolving or resuspending restricting materials. The cleaning tool was reported to generate acoustic power densities of up to  $2 \text{ W/cm}^2$ ,  
25 which is above the cavitation threshold for water at ambient temperature and pressure. See, US Patent 4,280,557. The tool, which consisted of an array of air-backed high power acoustic transducers of the type described by Widener, was designed to be deployed into the well on a wireline cable. See, Widener, M.W.,  
30 "The development of high-efficiency narrow-band transducers and arrays", *J. Acoust. Soc. Amer.*, **67**, 1051-7 (1980); Widener, M.W., "The development of a deep submergence air-backed transducer", *J. Acoust. Soc. Amer.*, **80**, 1852-3 (1986). The transducers described by Widener would be expected to operate in  
35 the frequency range 10-100 kHz. US Patent 5,676,213 disclosed the

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use of high power ultrasound to remove the filter cake formed by the drilling fluid during the drilling of a well in order to measure the pressure in permeable formations. The high power ultrasound was generated by a focussing transducer operating in 5 the frequency range 100-500 kHz and capable of operating at a peak input power of up to 1 kW. US Patent 5,727,628 disclosed an ultrasonic tool for cleaning producing wells. The wireline-deployable tool consisted of an array of magnetostrictive transducers operating in the frequency range 18-25 kHz 10 (preferably at 20 kHz) and emitting an acoustic power density in the range 8-12 W/cm<sup>2</sup>. The tool was also equipped with a pump to remove the debris of the fouling deposits disaggregated by the ultrasonic tool. US Patent 5,735,226 disclosed a method to prevent the fouling of ships and other marine structures by the 15 use of ultrasound over the frequency range 20-60 kHz. One demonstration of the technique was the location of a number of ultrasonic transducers on the hull of a ship over a period of 4 months. Over this time period the transducers, which were powered intermittently, gave effective relief from marine 20 fouling. US Patent 5,735,226 revealed no details of the power consumption of the transducers, but one embodiment of the invention consisted of the array being powered by a 9 volt battery. US Patent 5,889,209 disclosed the use of high power ultrasound to prevent biofouling of chemical sensors used in 25 aquatic environments. The ultrasound was generated by a transducer operating in the frequency range 10-100 kHz and yielding a sufficient power density (> 0.1-1 W/cm<sup>2</sup>) to drive acoustic cavitation. US Patent 5,889,209 disclosed the use of the acoustic cleaning technique to maintain the performance of a 30 dissolved oxygen sensor located in microbiologically active water for seven days. The transducer was located over the range 4-10 mm from the active membrane of the oxygen sensor and activated for a time period of 6-90 seconds over a time interval of 5-120 minutes.

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Several papers and patents have reported on the use of high power ultrasound to accelerate the dissolution of scale by chemical scale dissolvers applied in pipelines and producing oil wells. Paul, J.M. and Morris, R.L., "Method for removing 5 alkaline scale", *International Patent Application WO 93/24199*, 9 December, 1993 describes the use of low frequency (1.5-6.5 kHz) sonic energy to accelerate the dissolution of alkaline earth metal scales using scale dissolving solutions (typically containing the chelating agents EDTA or DTPA). Gunarathne, and 10 Gunarathne and Keatch have shown that the application of low-power ultrasound can increase the rate of dissolution of barium sulphate scale using commercially available scale dissolvers; the power density was claimed to be below that required to 15 cavitate the scale dissolving solution.

In conclusion, there appears to be no prior art that teaches or suggests either an acoustic scale sensor or an acoustic cleaning device located permanently or quasi-permanently in a well producing hydrocarbons. There appears to be no prior art of 20 teaches or suggests the concept of a sensor for hydrocarbon wells to monitor the formation of inorganic or organic scales, biofouling or corrosion and initiate a cleaning action. Additionally, there appears to be no prior art that teaches or suggests an on-line deposits monitoring and cleaning device 25 located on the surface facilities of a producing oil well using an ultrasonic transducer operating in its longitudinal mode and coupled to the produced fluids using a coupling material, such as an acoustic horn, to which the deposits adhere.

## SUMMARY OF THE INVENTION

5 It is an object of this invention to describe an apparatus that can be placed at various locations to monitor the deposition of scale and other deposits and preferably to remove such deposits.

According to the invention a deposit monitoring apparatus  
10 located in a hydrocarbon wellbore is provided comprising: an acoustic device adapted to operate in a resonance mode including a monitoring surface directly exposed to fluids in a hydrocarbon wellbore, wherein the deposition of material on the monitoring surface is monitored by measuring a change in resonance  
15 frequency of the acoustic device; and a power supply adapted to supply said monitor with electrical energy.

The acoustic device is preferably mounted either permanently or quasi-permanently in the wellbore.

20 According to another aspect of the invention, a deposit monitoring apparatus located in a hydrocarbon wellbore is provided, comprising: a deposit monitor adapted to measure deposition of material on a monitoring surface that is directly exposed to fluids in the hydrocarbon wellbore; a power supply adapted to supply said monitor with electrical energy; and a deposit removal system in communication with the deposit monitor adapted to at least partially remove the deposition from the monitoring surface, the deposit removal system being in a  
25 control loop with said deposit monitor.

In a preferred embodiment the deposit monitor is a high power ultrasonic transducer, operating in a longitudinal mode, coupled to the fluids produced from the well by a solid coupling device,  
35 such as an acoustic horn, for measuring the deposition of the

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organic and inorganic scales that form from the fluids produced in hydrocarbon wells. By longitudinal mode we mean that the surface of the device exposed to the fluid is move predominantly normal rather than parallel to the exposed surface.

5

The transducer is preferably designed to operate in the frequency range 10-250 kHz with a maximum acoustical power outputs of 10-500 W. The maximum power is preferably only used during the cleaning process for less than 10 seconds or even 10 less than 1 second. More preferably the frequency range is between 10kHz and 150kHz. The optimal frequency range is believed to lie within the range of 50 to 100 kHz. It was found that higher frequencies, particularly frequencies in the MHz region, are not applicable for permanent downhole deployment.

15

The growth of wellbore deposits is monitored by the decrease in the resonant frequency of the transducer with increasing thickness of deposit. The resonant frequency is conveniently determined from the real part of the admittance spectrum of the 20 transducer. The horn amplifies the effect of the scale deposit on the measured admittance of the transducer.

The term "horn" is used as a generic expression for a solid coupling device, sally consisting of a tapering end piece 25 mounted onto the body of the acoustic transducer. The horn can be bolted or glued to the body of the transducer material. The length of the horn is preferably some integer multiple of half the wavelength of the acoustic wave generated. The tapering can be achieved by cutting steps into the material or smoothly, 30 e.g., as exponential tapering.

The horn material can be chosen arbitrarily from a large variety of solid materials. It is however a preferred feature of the invention to have the horn tip made of a material that matches 35 the properties of the surrounding material, so as to ensure that

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the deposits on the surrounding material are accurately measured.

At least the tip of the horn is directly exposed to the wellbore  
5 fluid causing the deposition.

The transducer is able to detect inorganic deposits or scales, such as barium sulphate or calcium and organic deposits, such as waxes, at a thickness of approximately 100  $\mu\text{m}$ .

10 Scales can be removed from the transducer by operation at high power; the transducer is therefore able both to detect and clean deposits. The ultrasonic transducer is also able to clean scale from the surfaces of other components located at various  
15 positions in producing hydrocarbon wells, such as those made of glass, metal or plastics. The acoustic transducers can be permanently located in producing hydrocarbon wells and indicate the location and rate of scale deposition. The measurement of scale deposition can be used to direct scale treatment  
20 procedures, such as the placement of inhibitors or the application of scale dissolvers, and to warn of scale accumulation on critical downhole production equipment, such as chokes, sliding sleeves and separators. The acoustic scale sensor can also be used to determine the effectiveness of any  
25 treatment to remove scale or other wellbore deposits.

The control loop comprises either be a suitably programmed microprocessor or computer executing pre-programmed tasks. Or, it could include visual display units allowing a human operator  
30 to make decisions based on the measurements provided by the deposit monitor.

Permanently or quasi-permanently installed in a wellbore or below the surface of the Earth refers to installation that are

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fixed to the wellbore and thus can be retrieved to the surface only under great costs and even sacrifice of equipment.

These and other features of the invention, preferred embodiments 5 and variants thereof, possible applications and advantages will become appreciated and understood by those skilled in the art from the following detailed description and drawings.

#### DRAWINGS

10

FIGS. 1A-D are schematic illustrations of examples of acoustic devices, according to certain embodiments of the invention;

15 FIG. 2A shows the resonant frequencies of an acoustic device shown in FIG. 1B as measured by the real part of the admittance in air, water and kerosene;

20 FIG. 2B shows an enlarged part of FIG 2B;

FIG. 3 illustrates the shift of the resonant frequency with increasing scale deposition at a hydrostatic pressure of 272 bar (4000 psi);

25 FIG. 4 illustrates the shift of the resonant frequency with increasing wax deposition at ambient pressure;

30 FIG. 5 illustrates the shift of the resonant frequency after cleaning the tip of a sensor;

FIG. 6 illustrates the power supply used to remove deposits from a surface exposed to wellbore fluids;

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FIG. 7 illustrates a downhole installation in accordance with the invention;

5 FIG. 8 illustrates a sensor installation with self-cleaning equipment in accordance with the invention;

10 FIGs. 9A,B illustrate further sensor installations with self-cleaning equipment in accordance with the invention; and

15 FIG. 10 shows a schematic sensor adapted to further analyse wellbore deposits.

#### MODE(S) FOR CARRYING OUT THE INVENTION

##### (I) ACOUSTIC SCALE/DEPOSITS SENSOR

20 The scale (or deposits) sensor consists of an ultrasonic piezoelectric transducer operating in a longitudinal mode coupled to a suitable metal horn. The resulting ultrasonic device is characterised by a sharp resonant frequency, which can be conveniently determined by the measurement of the admittance 25 (or impedance) spectrum of the device. The resonance frequency of the appropriate longitudinal mode is sensitive to any solid deposit that forms on the tip of the horn and the magnitude of the frequency shift is a measure of the mass loading. These ultrasonic transducers typically operate in the frequency range 30 10-100 kHz and can deliver high levels of acoustic power, typically in the range 1-500 W, when driven by a high input alternating voltage at its resonant frequency.

35 FIG. 1 shows schematics of several types of acoustic horn attached to an ultrasonic transducer. The basic elements of the

- 20 -

scale deposit sensor 10 are a transducer 11 made of piezoelectric material, a power supply with electrodes 12 to cause oscillations of the transducer, and a horn 13. The horn is made of aluminum. The working surface of the transducer 131, on which the deposition of the scale is sensed, is the tip of the horn. In a downhole and surface installations, the tip 131 (or 141, 151, and 161 for the embodiments of Figures 1B, 1C, and 1D respectively) will be exposed to wellbore/production fluids and accumulate deposits.

10

The resonant frequency of the acoustic device operating in a longitudinal mode is determined by the size of the piezoelectric and the attached horn and the materials from which the piezoelectric and metal horn are constructed. The variants

15 differ in their respective horn design. The horn 13 shown in FIG. 1A has a stepwise tapering. In FIG. 1B, the tapering is smooth with an exponentially reducing diameter of the horn 14. The horn coupled to the ultrasonic piezoelectric transducer is made of aluminium. The resulting device has a sharp resonant 20 frequency in air of 40 kHz nominally and the area of the horn tip was 0.2 cm<sup>2</sup>. In FIG. 1C, the tapering is degenerated to a single step giving the horn 15 a pin-like shape. Other horn shapes can be envisaged, including the case where its thickness 25 is very much less than the wavelength of sound and the horn is a thin layer of material that couples the ultrasonic transducer to the bore hole fluids and their deposits.

Further indicated in FIG. 1 is the length of the horn as integer multiple N of half the wavelength ( $\lambda/2$ ) of the acoustic wave 30 generated by the transducer. FIG. 1D shows the case where the length of the horn 16 is very much less than  $\lambda/2$  and the horn tip 161 has the same area as the ultrasonic transducer.

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Table 1 shows the resonant frequency of the ultrasonic horns and the widths of the resonance at half peak height shown in FIG. 1A-C. The peak width of the resonance is typically 1-2% of the resonant frequency.

5

**Table 1.** Resonant frequencies in air of the ultrasonic transducers shown in FIG. 1A-C.

10

Transducer type in FIG. 1	Resonant frequency (kHz)	Width of resonance at half peak height (Hz)
A	19.86	21
B	39.04	52
C	54.63	96

FIG. 2 shows the resonant frequency of the acoustic sensor shown in FIG. 1B as measured by the real part of the admittance in

15 Siemens (S). The resonant frequency of the ultrasonic transducer is modified by the nature of the fluid in which it is immersed. FIG. 2 compares the resonant frequency of the ultrasonic transducer immersed in air, water and kerosene. The resonance frequency of the transducer decreases when the metal  
20 horn is immersed in a denser fluid and the resonance broadens with more viscous fluids. The fine structure (shown in FIG. 2B) on the admittance spectra measured when the transducer is immersed in water and kerosene at ambient pressure is caused by the attachment of small air bubbles to the horn.

25

FIG. 3 shows the shift in the resonant frequency of a transducer and metal horn with thickness of attached scale when the horn is immersed in water in a pressure vessel at a hydrostatic pressure of 4000 psi (270 bar). The resonant frequency of the 20 kHz

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transducer shifts by 85 Hz per millimetre of scale of density 4.50 g/cm<sup>3</sup>.

Further measurements show the variation of the shift in the 5 resonance frequency of a 40 kHz transducer as a function of scale thickness in water at ambient pressure for two scale types with densities of 2.75 and 4.50 g/cm<sup>3</sup>. The resonant frequency of the transducer decreases by 774 Hz per millimetre of scale of density  $\rho=2.75$  g/cm<sup>3</sup> and 966 Hz per millimetre of scale of 10 density  $\rho=4.50$  g/cm<sup>3</sup>.

The accumulation of inorganic scale can also be detected by a shift in the resonant frequency of a transducer when the horn is immersed in a liquid hydrocarbon. When comparing the admittance 15 spectra of a 40 kHz transducer and horn immersed in kerosene at ambient pressure with and without inorganic scale attached, it was found that the shift in the resonant frequency of the transducer is 1317 Hz per millimetre of scale of density  $\rho=4.50$  g/cm<sup>3</sup> in kerosene at ambient pressure.

20 The resonant frequency of an ultrasonic transducer and horn also decreases when organic deposits, such as wax, form on the tip of the horn. FIG. 4 shows the admittance spectra of a 40 kHz ultrasonic transducer and metal horn immersed in water at 25 ambient pressure with wax of various thicknesses attached to the tip of the horn. The resonant frequency of the transducer decreases by 180 Hz per millimetre of wax of density 0.79 g/cm<sup>3</sup> when the horn is immersed in water at ambient pressure.

### 30 (II) ACOUSTIC SCALE/DEPOSITS CLEANING

The inorganic and organic deposits that accumulate on the tip of the horn can be removed by applying a high alternating voltage to the transducer. The strain produced in the transducer and the 35 attached horn breaks the bond between the horn tip and the

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deposit and the tip is cleaned. The acoustic deposits sensor can therefore be self-cleaning. The acoustic scale/deposits sensor is also able to clean scale from the surfaces of other components, which are either in close proximity to the tip of 5 the horn or incorporated into it.

The scale was deposited on the tip of a metal horn connected to a 20 kHz ultrasonic transducer. The horn and transducer were housed in the cap of a cell that can be pressurised to 340 bar 10 (5000 psi). The area of the horn tip is  $2.87 \text{ cm}^2$ , the average scale thickness is 1.47 mm and the scale density is  $4.50 \text{ g/cm}^3$ . A high voltage was applied to the transducer and the horn was sonicated in a pressure cell at a hydrostatic pressure of 136 bar (2000 psi). All of the inorganic scale was removed from the 15 tip of the horn.

FIG. 5 compares the admittance spectra of the acoustic transducer and metal horn before and after acoustic cleaning at 136 bar (2000 psi). The resonant frequency of the ultrasonic 20 transducer and metal horn changed by 210 Hz after sonication.

The electrical power that is required by the transducer to remove the scale from the tip of the horn can be determined from the input voltage and current. The frequency of the input 25 voltage and current is 19.84 kHz, which compares to a value of 19.81 kHz obtained from the admittance spectrum of the cleaned horn. The scale, which consisted of a deposit with a density of  $4.50 \text{ g/cm}^3$  and a thickness of 1.47 mm, was removed from the metal horn at a hydrostatic pressure of 136 bar (2000 psi). FIG. 6 30 shows the input power waveform supplied to the transducer during the cleaning of the scale. The modulus of the time-averaged input electrical power of the waveform shown in FIG. 6 is 20.4 W.

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(III) SOME APPLICATIONS OF AN ACOUSTIC DEPOSITS SENSOR AND CLEANER

According to the invention a permanent scale/deposits monitor is  
5 provided. Ultrasonic transducers, of the type described above,  
operating over a range of frequencies, typically 10-150 kHz, can  
be permanently installed in a producing hydrocarbon well to  
determine the rate of accumulation of scale and other deposits  
(wax, asphaltene, etc.). The transducers can be deployed at  
10 various locations in the well, including surface production  
facilities such as subsea valves, risers, separators and any  
associated pipes and conduits, in order to determine the  
location of scale formation. The transducers can be used to  
determine the rate of accumulation of scale and other deposits  
15 and these measurements can be used to select the appropriate  
treatment to maintain the productivity of the well, such as the  
deployment of scale inhibitors or scale dissolvers. The deposits  
accumulated on the horn attached to the transducer can be  
cleaned periodically to maintain its sensitivity.

20

According to the invention the apparatus can be used in the  
maintenance of intelligent completions. More specifically, the  
ultrasonic sensor can be used to determine the accumulation of  
scale, wax or asphaltene on critical downhole equipment, such as  
25 chokes, valves and the sliding sleeves on intelligent completion  
systems. The measurements can be used to select an appropriate  
treatment to maintain the integrity and operation of the  
equipment, e.g., deployment of a scale dissolver to remove scale  
from critical components.

30

In FIG. 7 reference is made to an "intelligent" completion  
system deployed to control the flow of wellbore fluid into a  
production pipe.

- 25 -

FIG. 7 shows a schematic of part of an intelligent completion system. An intelligent completion allows active control of downhole processes such as flow rate measurements and control. A wellbore 70 is shown with a casing 701 installed. At certain 5 locations the casing 701 is perforated by holes 702 to allow wellbore fluid to enter the wellbore. Installed within the wellbore is a production pipe 71 with a slotted section 711. Wellbore fluid enters the production pipe via the slotted section 711. Mounted within the production pipe is a sliding 10 sleeve 712. The sliding sleeve 712 controls the flow of reservoir fluids into the production tubing from a particular section of the well. The flow rate, pressure and temperature of the production fluids are measured by a sensor sub 713 near the slotted section 711 into the tubing. The sliding sleeve 712 is 15 operated by a downhole electrical motor 714 that is powered by means of an electrical cable 721 from the surface 72.

One problem associated with the use of a sliding sleeve is the formation of wellbore deposits, such as inorganic scale or wax, 20 on the sleeve or its track. It is common practice to design the completion hardware such that the electric motor 714 is sufficiently powerful to remove small amounts of scale when the sleeve is moved. However, attempting to remove scale or other 25 deposits by scraping with the sleeve 712 may result in damage to the track and possible jamming. The location of an acoustic scale sensor 715 close to the sliding sleeve 712 will enable the accumulation of deposits on completion hardware to be assessed quantitatively through control equipment 722 located at the 30 surface. Transfer of energy and data signal between control equipment 722 and the sensor 715 is done via wiring 716 run with the production tubing. If scale accumulation on the sleeve is considered to be above a level at which it can be safely operated, then an external scale removal process may be required (e.g., application of a scale dissolver solution).

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Alternatively, the control equipment 722 could be used to activate the sleeve periodically or responsive to a threshold amount of deposit as measured by the scale sensor 715. In yet another alternative the control equipment 722 could at least 5 partly be incorporated into the downhole installation. By thus providing a direct feedback control between sleeve and deposit monitor 715, the amount of intervention from the surface can be reduced.

10 According to the invention, acoustic cleaning of scale and other deposits is provided. The ultrasonic transducer and associated horn can be used to remove scale and other deposits (wax, asphaltene, etc.) from critical components that are used in measurement devices exposed to wellbore/production fluids in the 15 wellbore or on the surface. The components can be part of measurement systems that are either permanently installed in producing hydrocarbon wells or surface facilities or temporarily exposed to the fluids produced by the hydrocarbon well, e.g., on a wireline-deployable tool. Critical components exposed to 20 wellbore fluids that may require cleaning include separation membranes, optical windows and electrical contacts such as electrodes.

FIG. 8 refers to a venturi-type flowmeter having a gamma-ray 25 sensor in its constriction section.

It shows a schematic of a gradio-venturi tube 81 located in the tubing 80 of a producing hydrocarbon well. The section of tubing 80 can be located either in a well or on surface 30 facilities. Located within the constriction formed by the venturi 81 is a gamma ray sensor 82. Details of those known components of a gradio-venturi can be found for example in US Patent No. 5,591,922. The gamma ray sensor, which consists of a gamma ray source 821 (frequently a dual energy source) and a 35 gamma ray detector 822, such as a photomultiplier tube. The

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gamma rays enter and leave the tube by means of nuclear windows 823 made of a material such as boron carbide. Gamma-ray devices as described above are known as such and described for example in the U.K. Patent Application No. 9919271.8.

5

A significant problem faced by the gamma ray density measurement is the accumulation of inorganic or organic scales on the nuclear windows 823. For example, the accumulation of small amounts of barium sulphate (barite) scale may result in a 10 serious overestimate of the density of the production fluids. Similarly, the accumulation of radioactive scales on the nuclear windows may give rise to erroneous measurements. The accumulation of organic scales, such as asphaltenes that may contain elements with of high atomic number, can also corrupt 15 the density measurement.

One solution to the problem of deposits accumulation on the nuclear windows 823 is to incorporate them into a high power ultrasonic transducer and horn as is the subject of the present 20 invention (see FIG. 1 above). FIG. 8 shows the two windows located in a hollow horn 824 and transducer 825; the windows 823 are cleaned by operating the transducer in its high power mode. The accumulation of deposits on the windows can be measured by a 25 shift in the resonance frequency of the transducer and horn, as described above.

The gradio-venturi tube of the type above can be located either on the surface or downhole, e.g., as part of an intelligent completion system.

30

FIG. 9 shows further examples of the use of an ultrasonic transducer and horn to clean measurement devices that may be deployed in a producing hydrocarbon well or at surface installation monitoring the flow of hydrocarbon from the well.

35

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FIG. 9A shows a schematic of an optical window 931 located at the tip of a horn 93 attached to an ultrasonic transducer 91. The optical window 931, which can be made of a suitably resistant material such as diamond or sapphire, can be connected 5 to a source and detector using an optical fibre 95 or other optical conduit such as a light pipe. The optical transmission of the window can be maintained by removing deposits of organic and inorganic scales with ultrasonic cleaning. The accumulation 10 of deposits on the optical window can be determined by either the decreased transmissivity of the window or the change in the admittance spectrum of the transducer 91 and horn 93 assembly. The optical windows can be located either in a producing oil well, on a permanent or quasi-permanent basis, or on the surface 15 facilities. The acoustic cleaning of optical windows can also be applied to wireline logging tools, such as the optical windows used in the Optical Fluid Analyser in Schlumberger's Modular Dynamics Formation Tester tool (described in U.S. Patent No. 4,994,671) or the windows used in the optical probes to monitor multiphase production from hydrocarbon wells, as described in 20 U.S. Patent No. 5,831,743.

FIG. 9B shows a schematic of an ultrasonic transducer 91 and horn 94 used to clean the membrane 961 of an ion selective electrode 96 that could be used to measure the activity of an 25 ionic species in the water produced from a hydrocarbon well. The performance of the membrane 961 is maintained by the cleaning action of the ultrasonic transducer 91 and horn 94, which are in close proximity to the membrane. The ultrasonic cleaning technique can be used to maintain the permeability of membranes 30 used to separate various components from the fluids produced from hydrocarbon wells, e.g., gas extraction membranes, oil-water separation membranes. Note that a separation membrane and electrode can also be incorporated into the horn coupled to a transducer. The separation membranes can be similarly located in

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a producing wellbore or in the surface facilities of a producing well.

According to the invention, a method for the identification of 5 scale type is provided. The resonant frequency of the transducer and horn responds to the mass of the attached deposits and it may not be possible to identify the type of scale deposit in the absence of other measurements. One of a variety of measurements could be used to identify the type of scale deposit accumulated 10 on the acoustic horn and thus enable acoustic scale sensor to measure the thickness of the deposit. Two examples are give. Firstly, a spectroscopic measurement could be employed, using an optical widow of the design shown in FIG. 9A. The scale type can identified by a total internal reflection spectroscopic 15 technique, such as infrared spectroscopy, or Raman spectroscopy, which, as reflection and scattering techniques, are insensitive to the thickness of the scale layer. A second possible technique is to use a second acoustic sensor, embedded in the acoustic horn, to measure the acoustic transit time through the scale 20 deposit.

FIG. 10 shows a schematic of the acoustic sensor used to measure the acoustic transit time  $\Delta T_t$  through the scale film. This acoustic sensor could be used either downhole or above ground on 25 the surface facilities. Pulsed ultrasound is emitted from an emitting transducer 981 and the reflections are collected by a second receiving transducer 982. The acoustic impedance  $Z$  of the scale layer 99 can be estimated by the measured values of the mass  $W$  of scale attached to the acoustic horn 97 and  $\Delta T_t$ . The 30 thickness of scale  $h$  attached to the horn is related to  $W$  by

$$[1] \quad h = \frac{W}{\rho_s A}$$

- 30 -

where  $\rho_s$  is the density of the scale and A is the area of the tip of the horn. The thickness h is related to  $\Delta T_t$  by

$$[2] \quad h = \frac{\Delta T_t V}{2}$$

5

where V is the velocity of sound in the scale layer. The combination of eqn. [1] and [2] gives

$$[3] \quad Z = \rho_s V = \frac{2W}{\Delta T_t A}$$

10

The scale type can be discriminated by the measured value of Z. Table 4 shows the values of the acoustic impedance Z as a function of scale type. When Z is identified the thickness h of the scale deposit can be calculated using eqns. [1] or [2] using 15 the known values of V and  $\rho_s$ .

**Table 4.** Values of the acoustic impedance Z for various inorganic scales.

20

Scale type	Acoustic impedance Z (kg/m <sup>2</sup> s × 10 <sup>-6</sup> )
calcite	17.6
anhydrite	18.0
celestite	19.1
barite	19.9

According to the invention monitoring scale/deposits removal techniques are provided. The acoustic scale sensor can be used to evaluate the efficiency of an external scale removal 25 treatment process, such as a scale dissolver solution or a physical scale removal technique. The scale removal treatment can be monitored in real time using the change in the resonant frequency of the transducer and horn. The acoustic scale monitor

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can therefore be used as part of a scale maintenance service that monitors scale accumulation and evaluates the cleaning/removal process. The maintenance service can be applied to the accumulation of scale both in a producing wellbore or in  
5 the surface equipment.

According to the invention, fluid composition and pressure effects can be determined. The resonant frequency of the ultrasonic transducer and horn with no deposits attached depends  
10 on the composition of the fluid with which it is in contact and its hydrostatic pressure. A change in the composition of the produced fluid or its hydrostatic pressure may therefore obscure the change in resonant frequency due to the accumulation of inorganic or organic deposits. A change in resonant frequency  
15 due to a change in fluid properties can be measured using a second matched transducer and horn, which is in close proximity to the scale detector. The second transducer is cleaned frequently to ensure that the horn is always free from inorganic and organic scales and that the changes in its resonant  
20 frequency are solely caused by changes in fluid composition and pressure.

Surface Modification of Acoustic Horn. An important aspect of a scale/deposits sensor permanently installed in a producing  
25 hydrocarbon well or in the surface facilities is that the rate of accumulation of deposits must be the same as that of the region of the wellbore it is monitoring. The composition and morphology of the surface of the tip of the horn should be such as to give the same rate of scale accumulation as the solid  
30 surfaces in the close environs of the sensor. The surface of the horn tip should be suitably controlled by the choice of material and/or coating. The material and coating used to fabricate the horn should be able to withstand repeated sonication.

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Size of Transducer and Horn. The size of an ultrasonic transducer and horn may be a critical issue for the permanent placement of such a device for scale/deposits monitoring. The size of the transducer and horn are largely determined by the 5 desired frequency of operation and the materials used to them. High power ultrasonic transducers and horns in the size range 5-6 cm, which operate in the frequency range 89-113 kHz, have been reported by Lal and White. See, Lal, A. and White, R.M., "Silicon microfabricated horns for power ultrasonics", *Sensors 10 and Actuators, A54*, 542-546 (1996). The acoustic horns were microfabricated from silicon wafers.

While preferred embodiments of the invention have been described, the descriptions and examples are merely illustrative 15 and are not intended to limit the present invention.

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CLAIMS

What is claimed is:

- 5        1. A deposit monitoring apparatus located in a hydrocarbon wellbore comprising:
  - 10        an acoustic device adapted to operate in a resonance mode including a monitoring surface directly exposed to fluids in a hydrocarbon wellbore, wherein the deposition of material on the monitoring surface is monitored by measuring a change in resonance frequency of the acoustic device; and
  - 15        a power supply adapted to supply said monitor with electrical energy.
- 15        2. The apparatus of claim 1, wherein the acoustic device is mounted either permanently or quasi-permanently in the wellbore.
- 20        3. The apparatus of claim 1, wherein the acoustic device operates in a longitudinal mode.
- 25        4. The apparatus of claim 3, wherein the acoustic device further comprises a transducer, and a focussing element coupled to the transducer.
- 30        5. The apparatus of claim 4, wherein the focussing element is an acoustic horn.
- 30        6. The apparatus of claim 1, wherein the resonance frequency of the acoustic device is in the range of 10 kHz to 150 kHz.

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7. The apparatus of claim 6 wherein the resonance frequency of the acoustic device is in the range of 50 kHz to 100 kHz.

5 8. The apparatus of claim 1, wherein the monitoring surface is located on or near one of the following devices switches, valves, sleeves, mandrels, downhole separators and sensors located in the wellbore.

10 9. The apparatus of claim 1 further comprising a deposit removal system adapted to at least partially remove the deposition from the monitoring surface, the deposit removal system being in a control loop with said deposit monitor.

15 10. The apparatus of claim 9, wherein the deposit removal system includes a deposition inhibiting or removing chemical agent.

20 11. The apparatus of claim 9, wherein the deposit removal system uses the acoustic device to exert a physical force onto the deposited material.

25 12. The apparatus of claim 9, wherein the deposition removal system is near a sensor having a surface exposed to the fluids and the deposition removal system is adapted to remove deposits from said exposed surface.

30 13. The apparatus of claim 12, wherein the sensor is selected from a group comprising optical sensors, electro-chemical sensors, or acoustic sensors.

14. The apparatus of claim 11, wherein the exposed sensor surface is selected from a group comprising optical windows, membranes, or sensitive areas of acoustic sensors.

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15. The sensor of claim 1, wherein the sensor includes an additional sensing system to analyze material deposited on the monitoring surface.

5 16. A deposit monitoring apparatus located in a hydrocarbon wellbore, comprising:

a deposit monitor adapted to measure deposition of material on a monitoring surface that is directly exposed to fluids in the hydrocarbon wellbore;

10 a power supply adapted to supply said monitor with electrical energy; and

15 a deposit removal system in communication with the deposit monitor adapted to at least partially remove the deposition from the monitoring surface, the deposit removal system being in a control loop with said deposit monitor.

17. The apparatus of claim 16, wherein the monitoring surface is located on or near one of the following devices: switches, valves, sleeves, mandrels, downhole separators and 20 sensors located in the wellbore.

18. The apparatus of claim 16 wherein the deposit monitor further comprises an acoustic device adapted to operate in a resonance mode, wherein the deposit monitor measures deposition 25 of the material on the monitoring surface by measuring a change in resonance frequency of the acoustic device.

19. The apparatus of claim 18, wherein the acoustic device operates in a longitudinal mode.

30

20. The apparatus of claim 18, wherein the acoustic device further comprises a transducer, and a focussing element coupled to the transducer.

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21. The apparatus of claim 18, wherein the resonance frequency of the acoustic device is in the range of 10 kHz to 150 kHz.

5 22. The apparatus of claim 18, wherein the deposit removal system includes a deposition inhibiting or removing chemical agent.

10 23. The apparatus of claim 18, wherein the deposit removal system includes elements adapted to exert a physical force onto the deposited material.

15 24. The apparatus of claim 18, wherein the deposition removal system is near a sensor having a surface exposed to the fluids and the deposition removal system is adapted to remove deposits from said exposed surface.

20 25. The apparatus of claim 18, wherein the sensor is selected from a group comprising optical sensors, electro-chemical sensors, or acoustic sensors.

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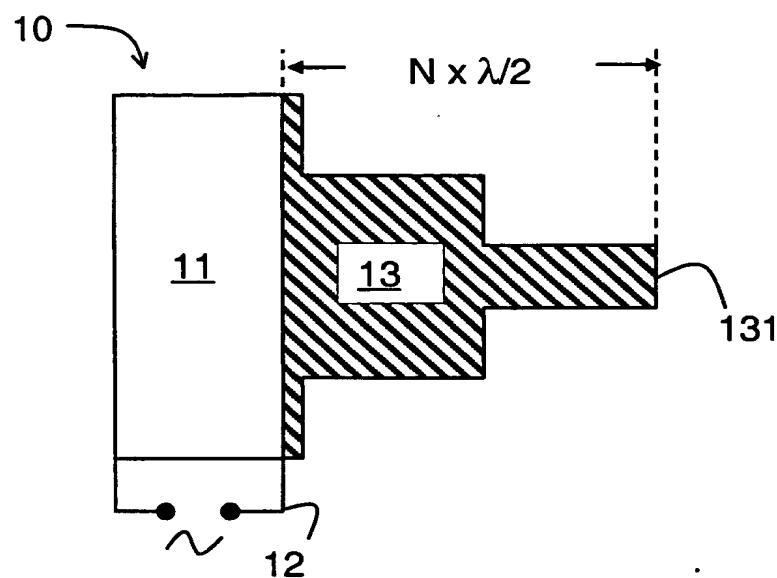


FIG. 1A

FIG. 1B

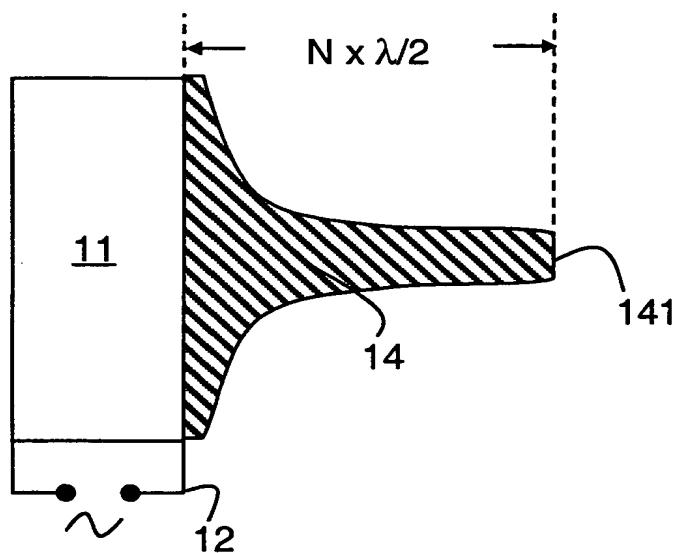
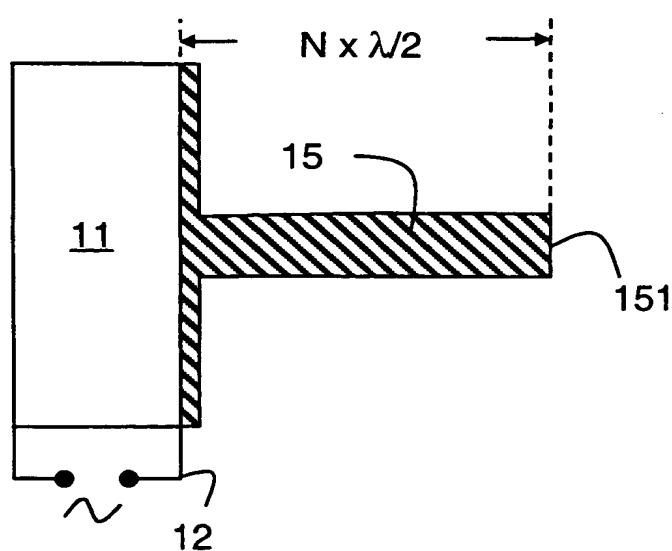


FIG. 1C



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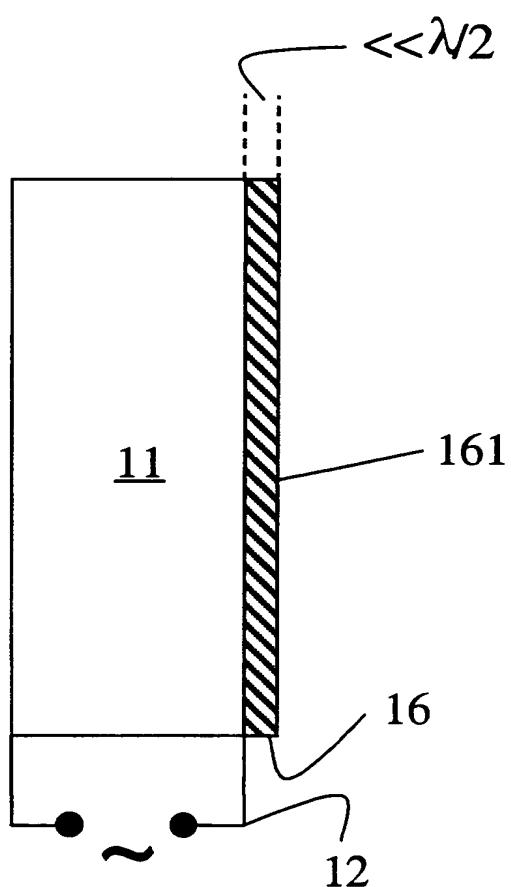


FIG. 1D

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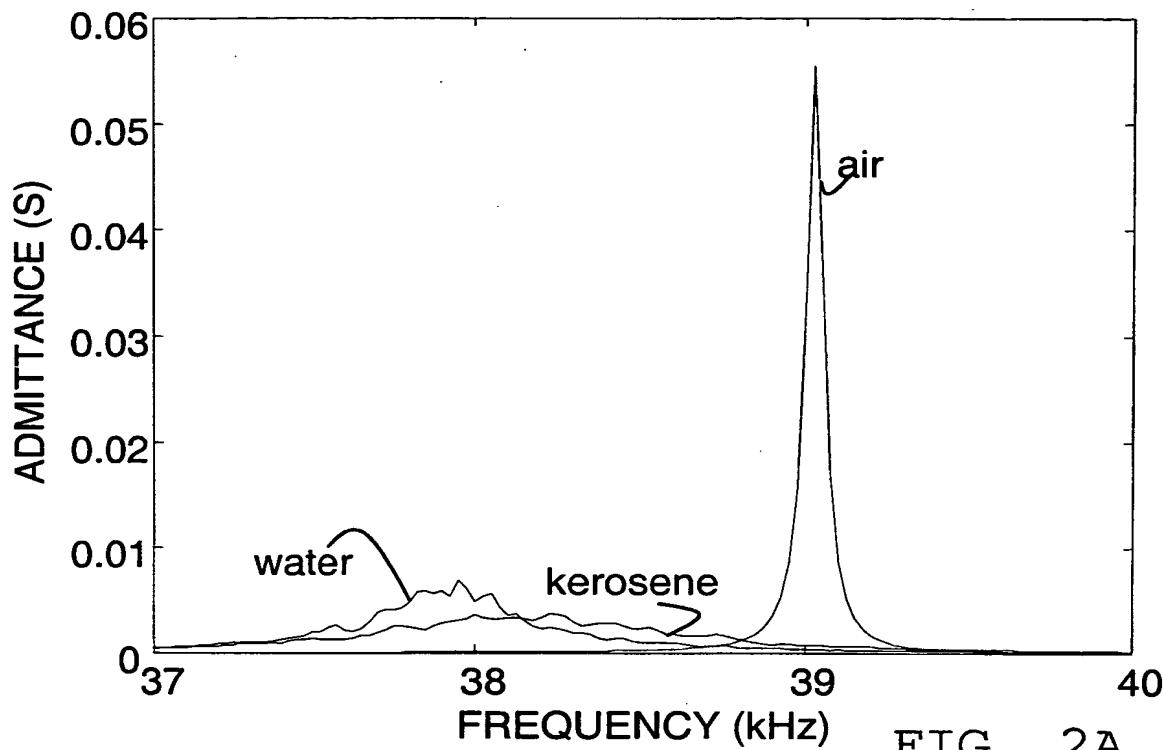


FIG. 2A

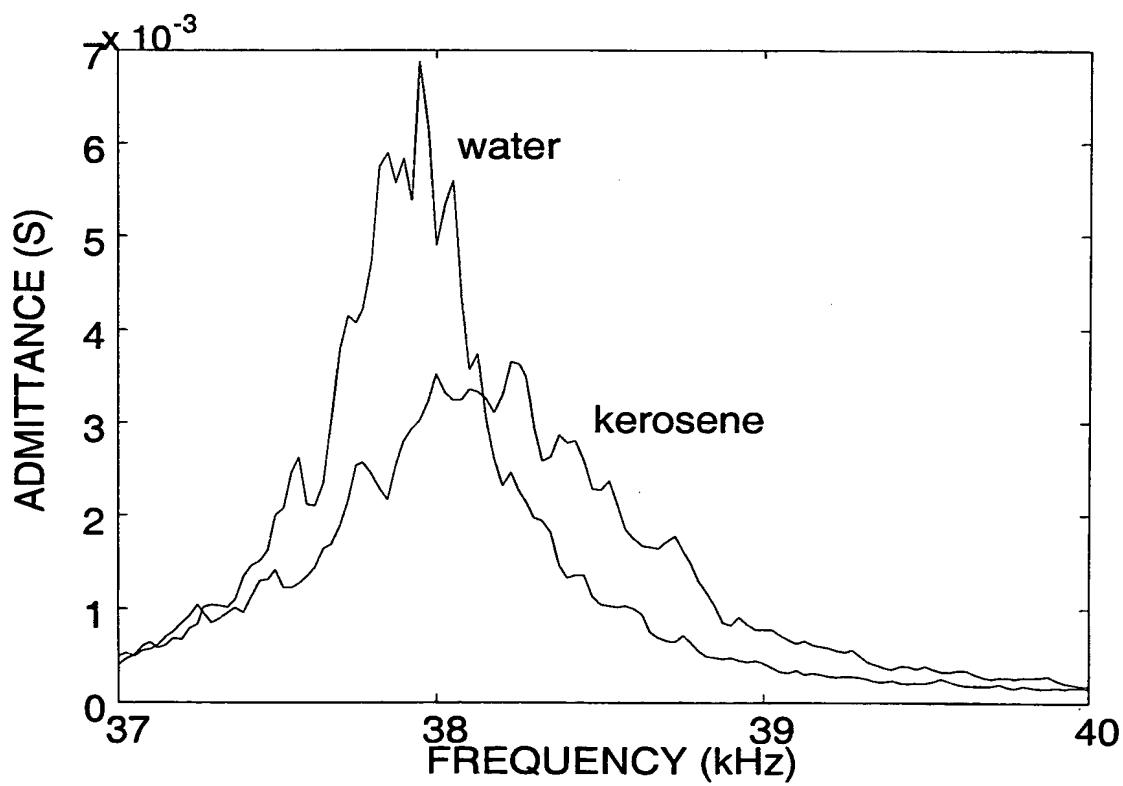


FIG. 2B

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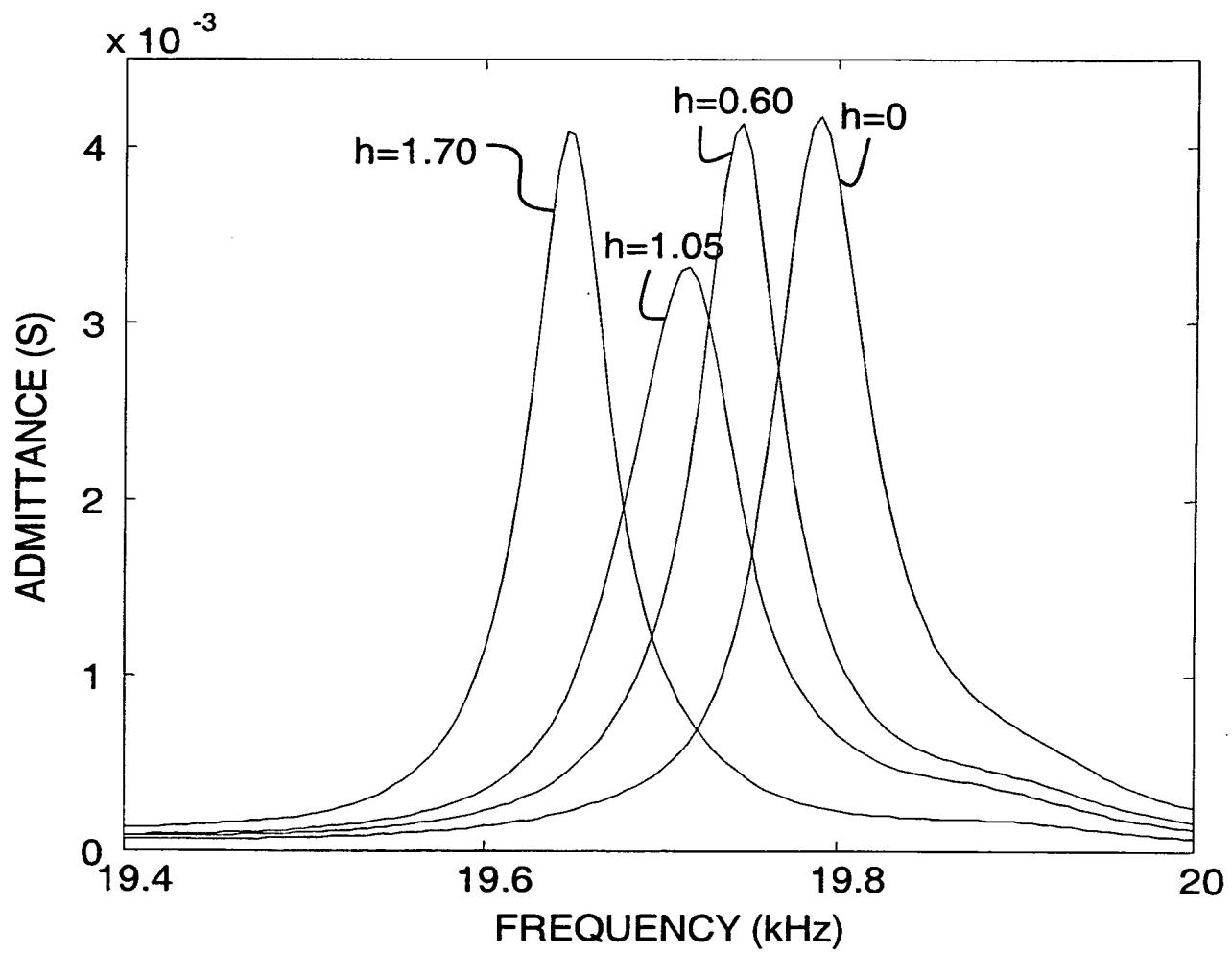


FIG. 3

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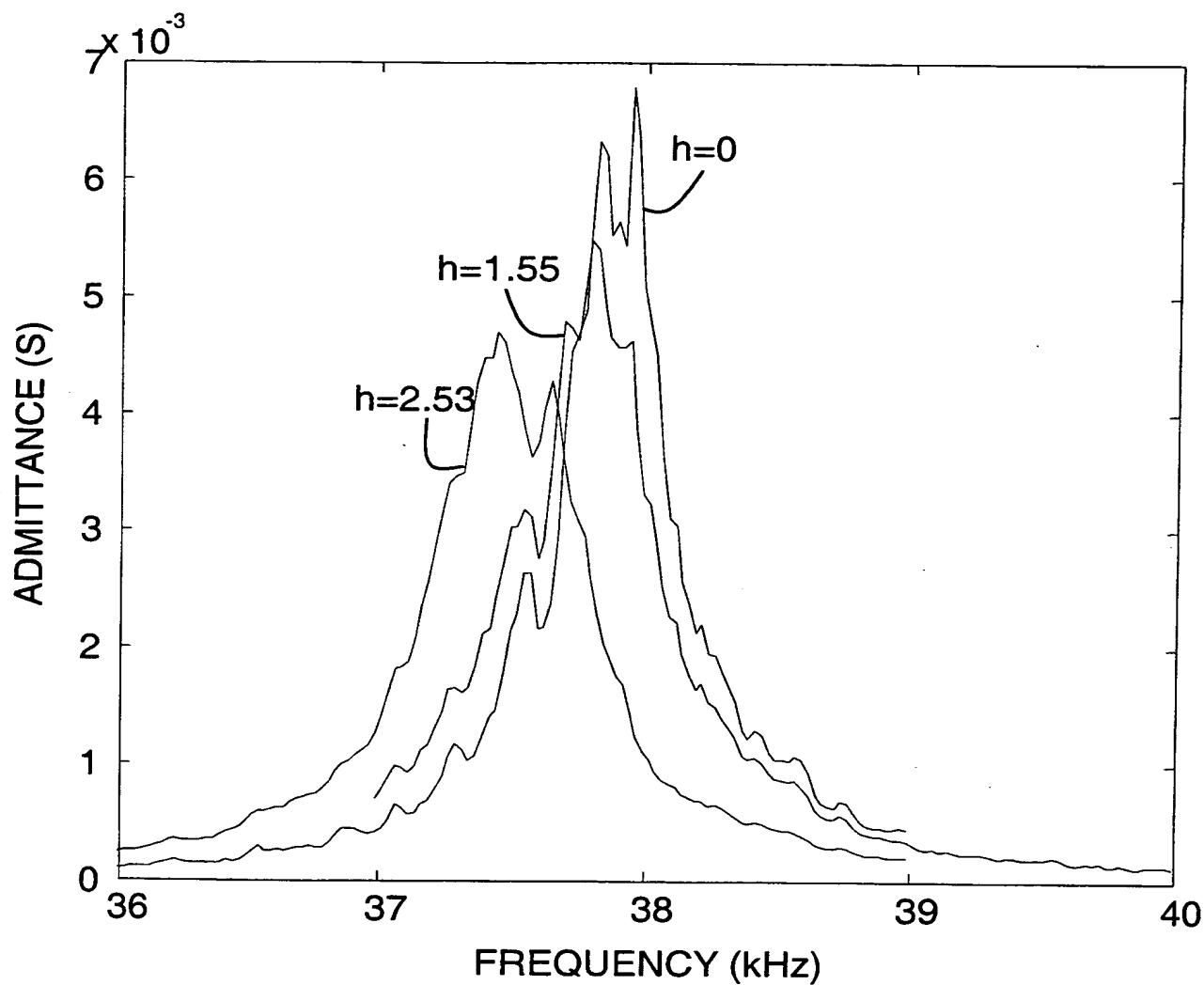


FIG. 4

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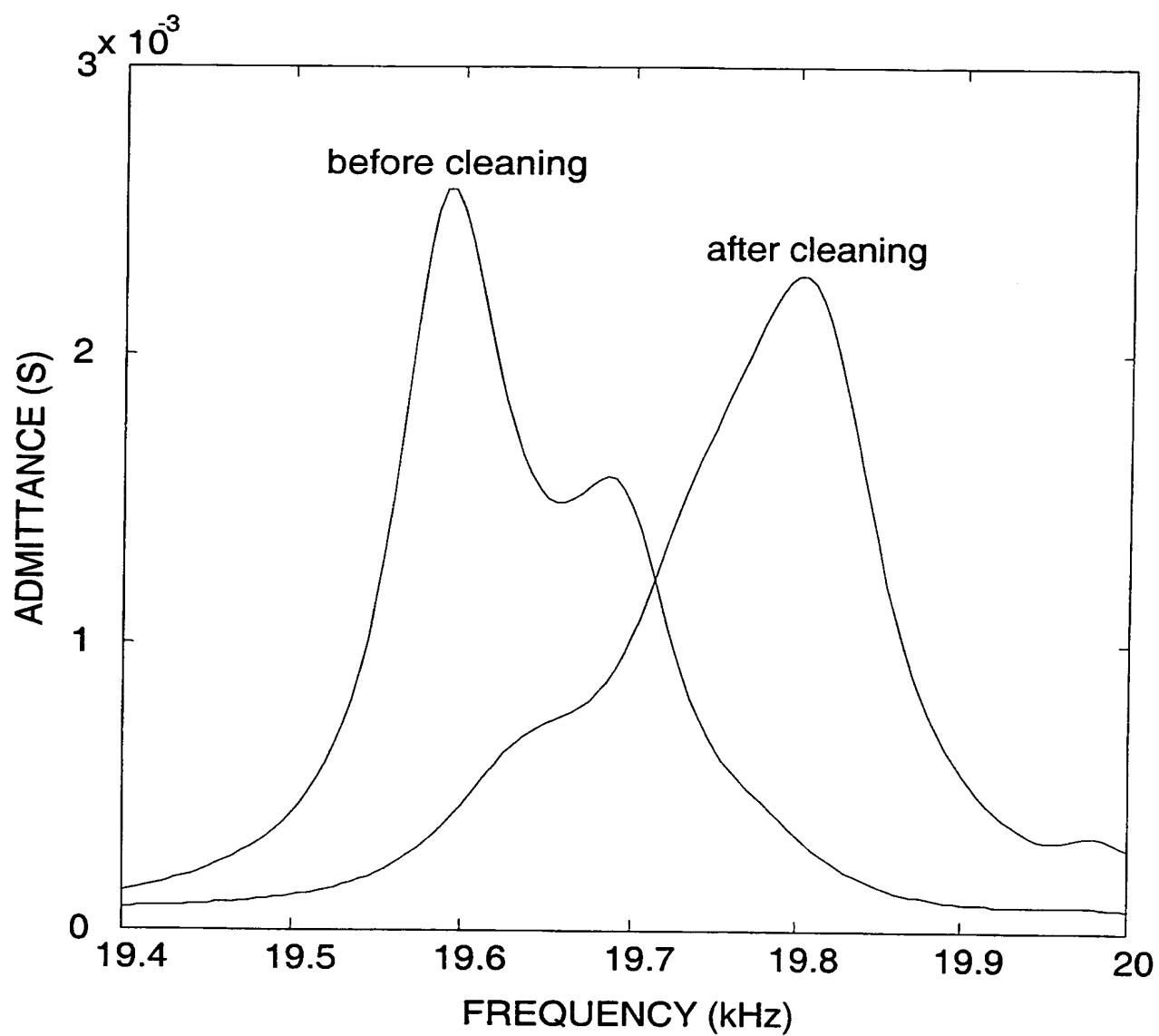


FIG. 5

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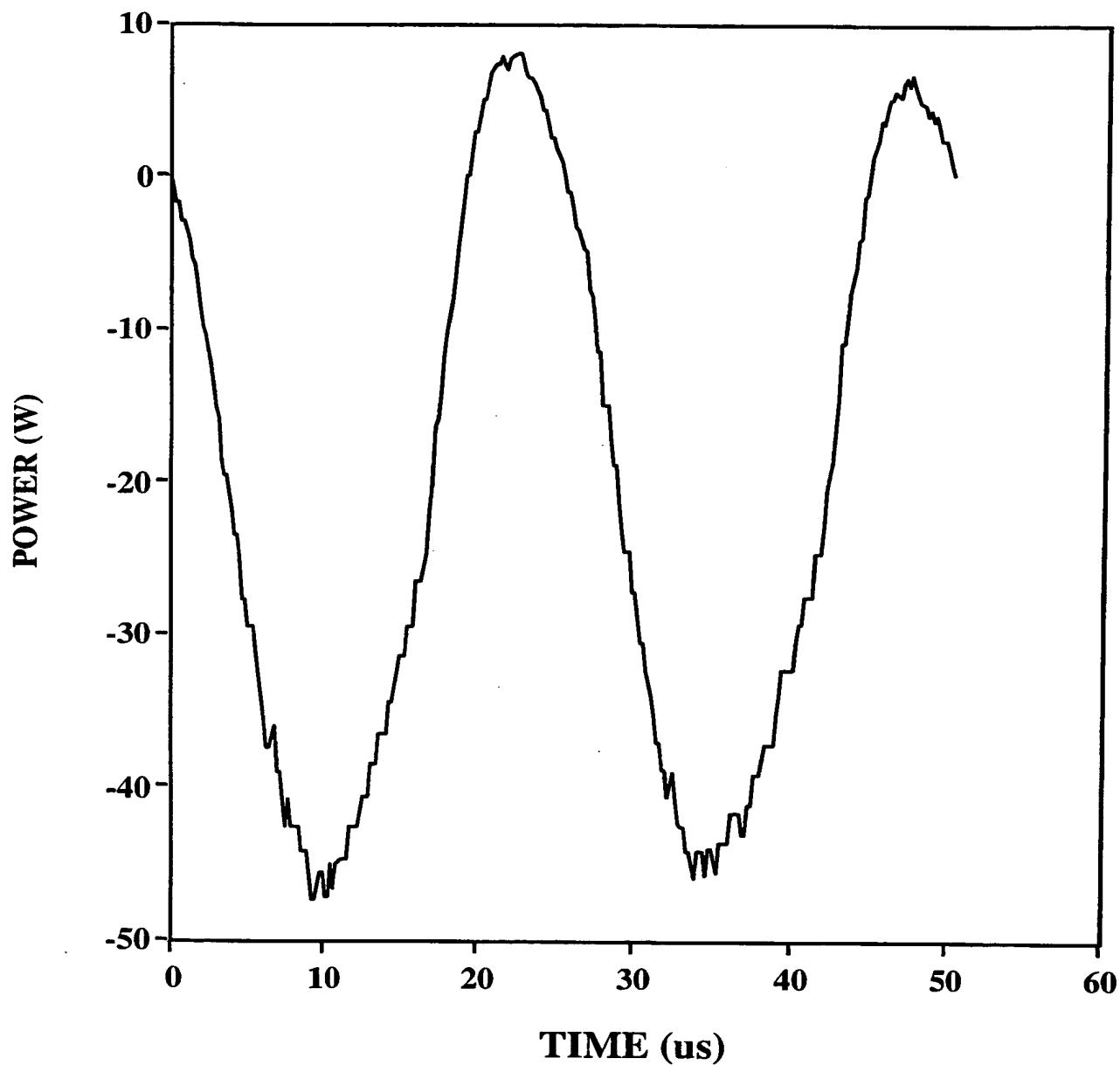


FIG. 6

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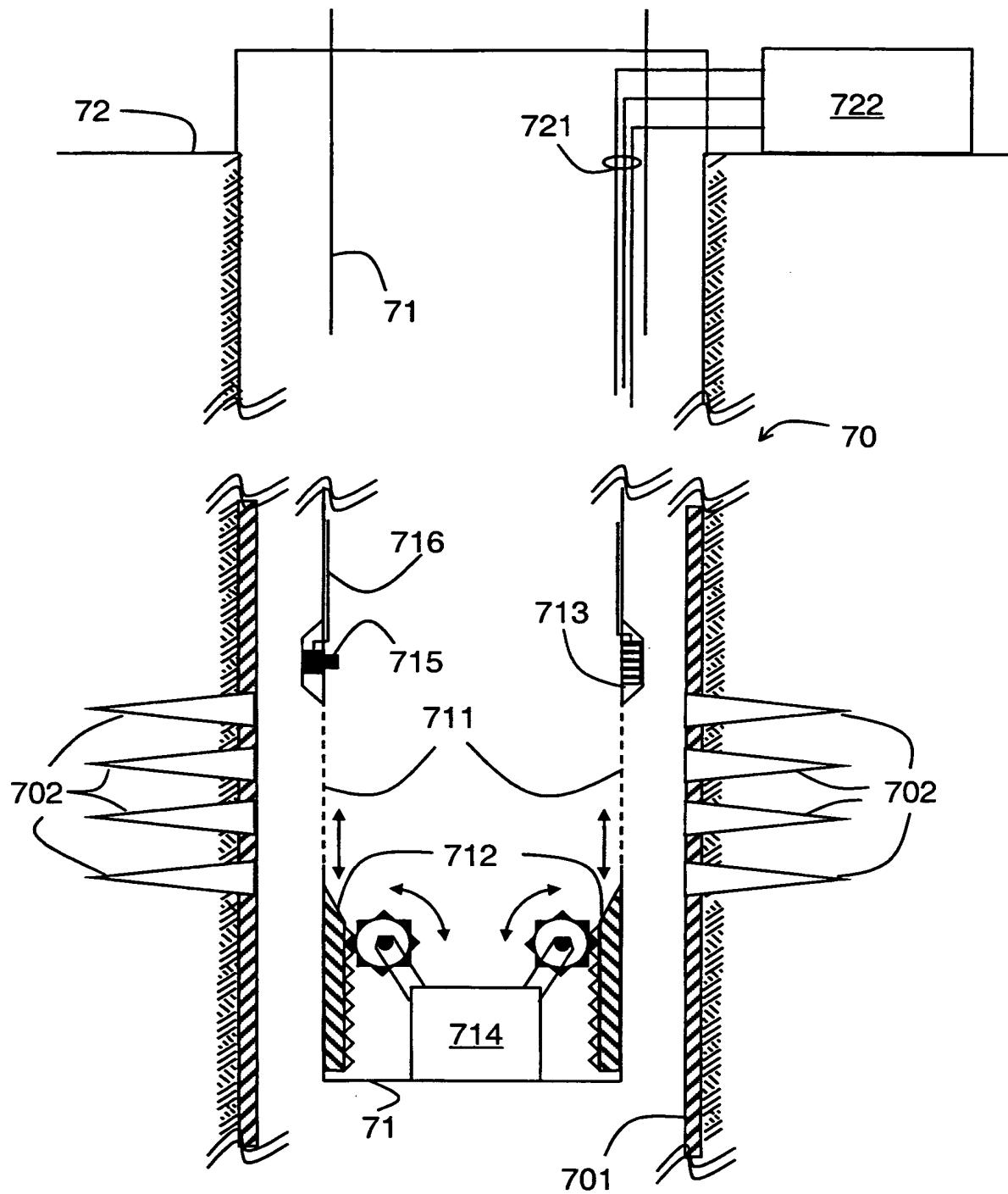


FIG. 7

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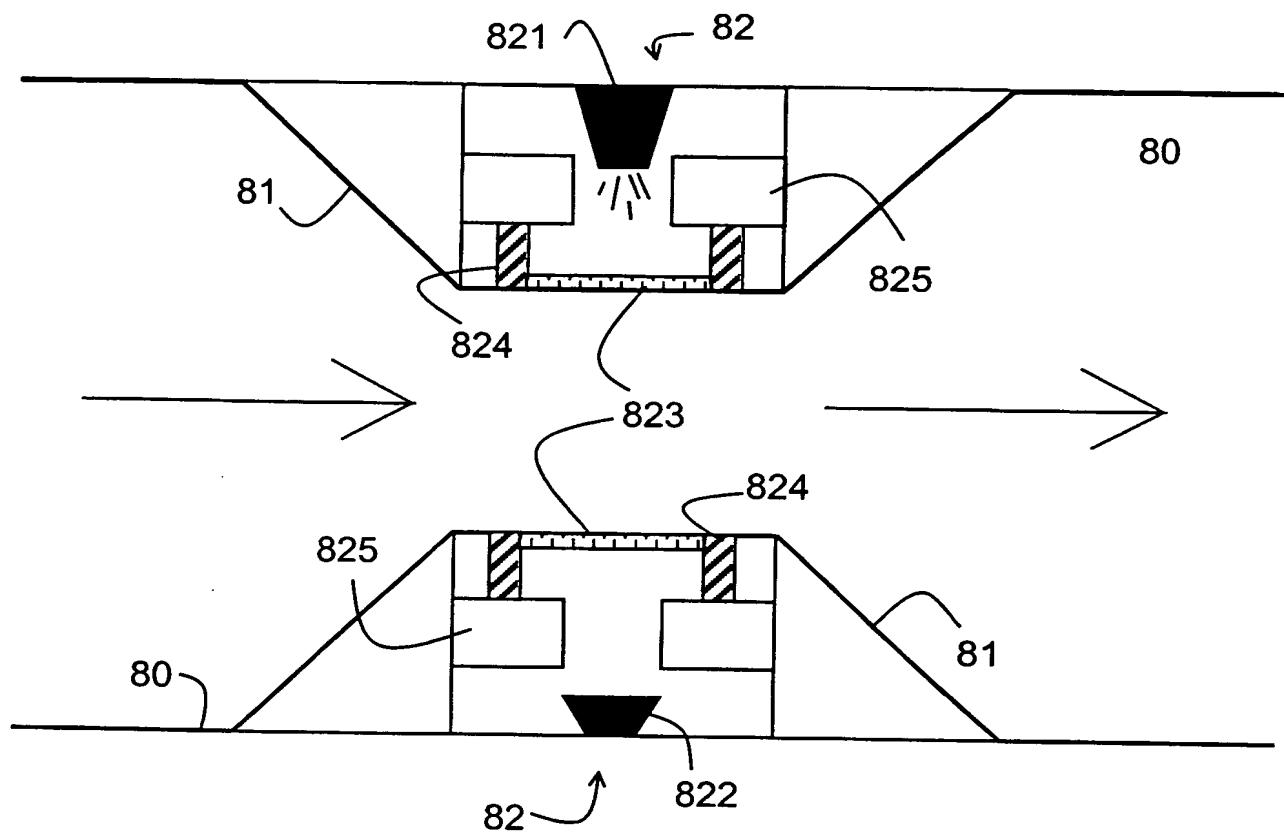


FIG. 8

10/11

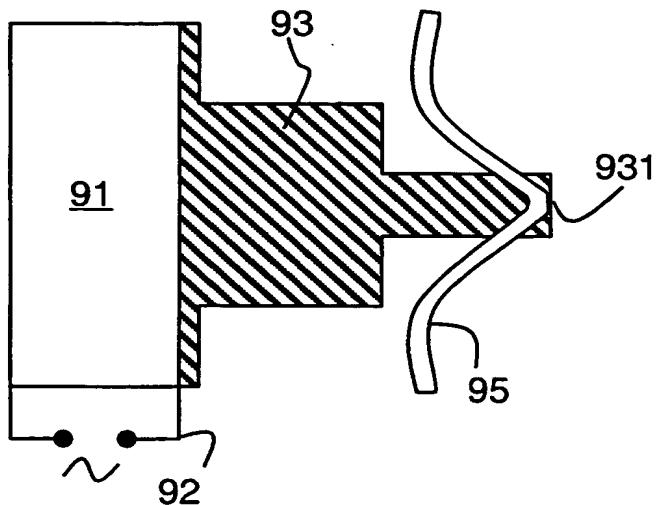


FIG. 9A

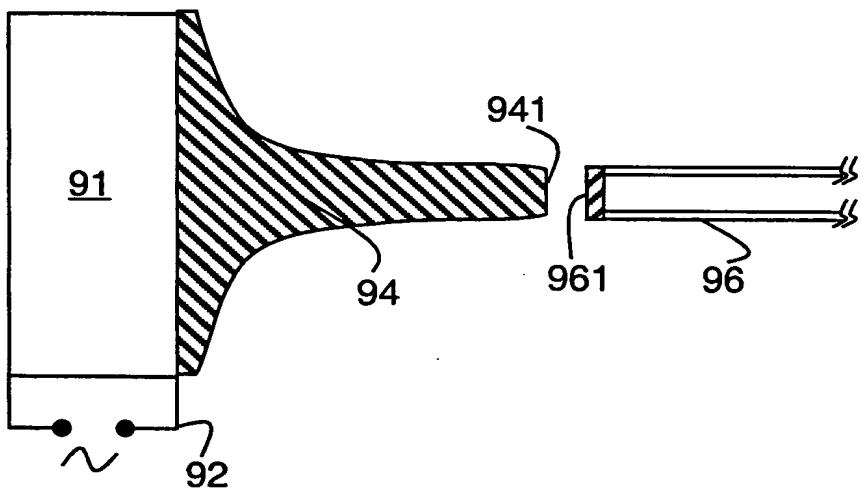


FIG. 9B

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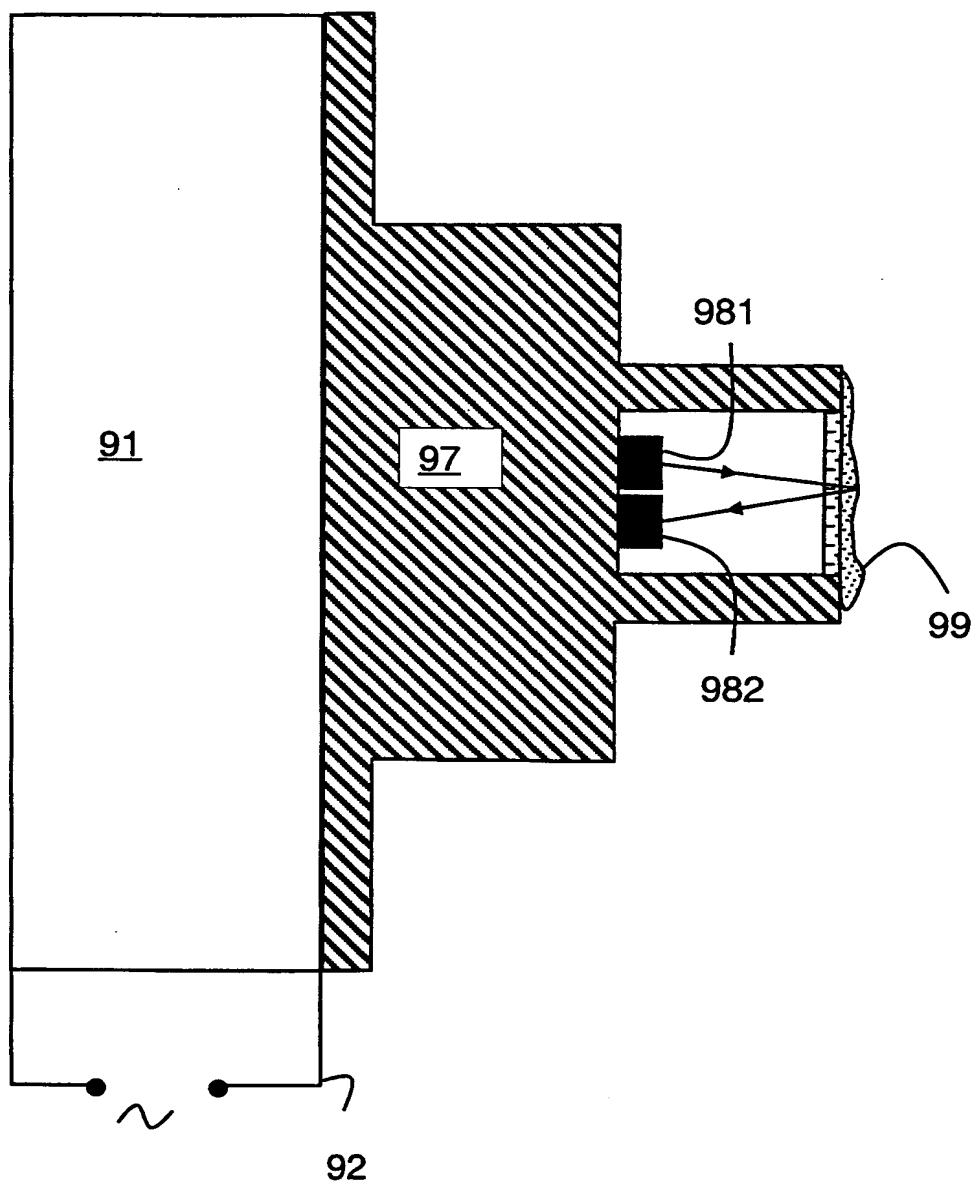


FIG. 10

# INTERNATIONAL SEARCH REPORT

I.	National Application No PCT/GB 00/04128
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A. CLASSIFICATION OF SUBJECT MATTER					
IPC 7	G01N29/02	G01G3/16	B08B7/02	E21B37/00	G01N5/00
G01N33/28					

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01N G01G B08B E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 661 233 A (SPATES JAMES J ET AL) 26 August 1997 (1997-08-26) cited in the application column 2, line 30 - line 38 column 4, line 10 - line 25 column 8, line 20 - line 62 column 13, line 20 - line 28 column 13, line 55 - line 65 column 14, line 4 - line 38  -/-	1,16

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
13 February 2001	21/02/2001
Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel: (+31-70) 340-2040, Tx. 31 651 epo nl. Fax: (+31-70) 340-3016	Hocquet, A

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 00/04128

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EMMONS ET AL.: "on-site, near real time monitoring of scale deposition" PROCEEDINGS OF SPE 1999 CONFERENCE 'PRODUCTION OPERATIONS AND ENGINEERING', vol. 2, 3 - 6 October 1999, pages 389-394, XP000979810 Houston (USA) cited in the application page 392, column 1, paragraph 4 -column 2, paragraph 3 page 390, column 2, paragraph 1 - paragraph 2 ---	1,16
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X	US 5 646 338 A (DECLERCQ GHISLAIN ET AL) 8 July 1997 (1997-07-08) column 1, line 19 - line 54 column 5, line 50 - line 60 column 6, line 17 - line 39 column 8, line 30 - line 51 column 9, line 12 - line 43 ---	16
A	US 5 595 243 A (MAKI JR VOLDI E ET AL) 21 January 1997 (1997-01-21) column 4, line 38 - line 41 column 5, line 5 - line 16; figures 3-5 ---	1,16
A	US 5 159 838 A (LYNNWORTH LAWRENCE C) 3 November 1992 (1992-11-03) column 1, line 10 - line 19 column 12, line 20 - line 34 column 1, line 63 -column 2, line 4 column 10, line 20 - line 45; table I ---	3-6
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International Application No  
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